ELECTRO-COAGULATION TREATMENT OF PROCESS WASTEWATER PRODUCED FROM WATER-BASED PAINT INDUSTRY

BY

AHMED M. AL-SAWALHA

A Thesis Presented to the

DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CIVIL ENGINEERING

April 2011

KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS

DHAHRAN 31261, KINGDOM OF SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

This thesis, written by

AHMED M. AL-SAWALHA

under the direction of his Thesis Advisor and approved by his Thesis Committee, has been presented to and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

Thesis Committee

Dr. Alaadin A. Bukhari, Chairman

Dr. Muhammad H. Al-Malack, Co-Chairman

Dr. Nabil S. Abu Zaid, Member

Dr.Mohammed S. Al-Suwaiyan, Member

Dr. Muhammad S. Vohra, Member

Dr. Nedal T. Ratrout 30 APR 2011
Chairman, Department of Civil Engineering

Dr. Salam A. Zummo
Dean, College of Graduate Studies

4/5/11
Date

Dedicated to

My Beloved Wife

ACKNOWLEDGEMENT

All praise is to Allah Subhanahu wa Ta'ala, for giving me the courage and strength to successfully complete my research work.

First and foremost I want to thank my advisor Dr. A.A. Bukhari. It has been an honor to be his student. He has taught me, both consciously and un-consciously, how good experimental is done. I appreciate all his contributions of time and ideas to make my master experience productive and stimulating. The joy and enthusiasm he has for his research was contagious and motivational for me. I am also thankful for the excellent example he has provided as a successful professor. . I would like also to express my gratitude to my co- advisor, Dr. M. H. Al-Malack, whose expertise, knowledge, and patience, added considerably to my graduate experience. I'm really grateful for his continuous support and encouragement through the execution of this work and for all the courses he taught me.

I would also like to acknowledge Dr. Abuzaid for his collaboration and providing me with the impressive crystal growing skills. Special thanks are also extended to Dr. Al-Suwaiyan and Dr. Vohra, for their time and interest and the continual support.

My time at KFUPM was made enjoyable in large part due to the many friends and groups that became a part of my life. I am grateful for time spent with friends,Lastly, I would like to thank my parents for all their love and encouragement. And most of all for my loving, supportive, encouraging, and patient wife whose faithful support during all stages of this master is so appreciated. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

THESIS ABSTRACT

NAME	**Ahmed M. Sawalha**
TITLE OF STUDY	**Electro-coagualtion Treatment of Process Wastewater Produced from Water-Based Paint Industry**
MAJOR FIELD	**Civil Engineering**
DATE OF DEGREE	**May, 2011**

A study was conducted to assess the potential of electrocoagulation on the removal of organic matter from paint industry wastewater. The electrochemical process was carried out in a lab-scale reactor provided with stainless steel electrodes. The effects of current, contact time, iron production and electrolyte concentration were investigated to remove the pollutants. The optimum operating parameters were achieved at 0.6 A and contact of time 20 min where the COD, TSS and turbidity removal efficiencies were 75%, 92% and 91%, respectively. To determine the effect of conductivity on the optimum operating parameters, different concentrations of NaCl namely 1000, 2000 and 3000 mg/l were added to determine the removal efficiencies for the COD, TSS and Turbidity. The results obtained showed that the increase in conductivity had no significant effect in the removal efficiency. Also, the pH values had increased due to hydrogen evolution at the cathode as a function of time and current density. However, pH values did not exceed the value of 8.73.

Master of Science Degree
King Fahd University of Petroleum & Minerals
Dhahran, Saudi Arabia
April , 2011

خلاصة الرسالة

الاسم: **احمد محمد الصوالحة**

عنوان الدراسة: **معالجة المياه الصناعية الناتجة من مصانع الدهانات المائية بواسطة التخثير الكهربائي**

التخصص: **الهندسة المدنية**

تاريخ الرسالة: **مايو، 2011**

اجريت دراسة لتقدير امكانية التخثير الكهربائي على إزالة المواد العضويه من المياه الناتجة من مصانع الدهانات ذات الاساس المائي ، وقد تم إجراء العملية الكهروكمياوية بواسطة مفاعل غير تدفقي مزود بأقطاب مصنوعة من الحديد، حيث تم دراسة تاثير التيار ومدة التعرض وكمية الحديد وتركيز المحلول الكهرولي على إزالة الملوثات، حيث اظهرت الدراسة أن المعايير التشغلية الامثل قد تم تحقيقها عند تيار 0.6 امبير عند 20 دقيقة حيث كانت نسب ازالة المواد العضوية والمواد الكلية العالقة والعكورة 75% و 92%و 91% على التوالي. ولتحديد تأثير الايصالية الكهربائية على المعايير التشغيلية الامثل فقد تم اضافة عدة تراكيز مختلفة من كلوريد الصوديم وبالتحديد 2000 و 3000 و4000 ملفم لكل ليتر لدراسة هذا التاثير على نسب ازالة المواد العضوية والمواد الكلية العالقة والعكورة، حيث اظهرت النتائج ان زيادة الايصالية الكهربائية لم ينتج عنها اي تأثير في عملية الازالة. لقد تم ايضا ملاحظة ان قيم درجات الحموظة ازدات بسبب تكون ايون الهيدروجين على الكائود، حيث أن هذه الزيادة تعتمد على قيمة التيار الكهربائي وزمن العملية، ولوحظ أن قيم درجات الحموضة لم تزد عن 8.73.

درجة الماجستيرفي الهندسة
جامعة الملك فهد للبترول والمعادن
الظهران ، السعودية
ابريل ، 2011

CHAPTER 1

INTRODUCTION

Paint industrial sector is one of the important industrial sectors in Saudi Arabia. The paint industry has undergone major development due to the construction boom in the kingdom, which created strong demand for paints. Currently, the kingdom has become one of the major exporters of paint especially, to the Middle East. The paint industry affects different sectors such as building and construction sector (e.g., household paint), transportation sector (e.g., roads paint), factories, refineries, desalination plants, offshore installations (industrial and marine paints), etc. The paint industry in Saudi Arabia produces a wide range of finished and intermediate products such as pigments, distempers, plastic emulsion, enamel, undercoat, primers, rubber paint, air craft paint, marine paint, anticorrosive paint, antifouling paint, etc.

There are 87 paint factories distributed in Kingdom of Saudi Arabia.

Environmental problems related to the paint industry are mainly caused by discharge of wastewater. Paint processing employs a variety of chemicals depending on the nature of the raw material and product. Due to the varying degree of chemicals used, the wastewater contains appreciable concentrations of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), suspended solids, toxic compounds, color and metals. Wastewater from paint industry can be hazardous to the environment. It harms marine life, wildlife and contaminates the soil, groundwater and the food chain if released without a proper treatment (Abu Hassan, 2008).

Many technologies have been used and investigated to treat the industrial paint wastewater. These include Wet Air Oxidation (WAO) (Abu Hassan, 2008), bio-oxidation (Brown et al.,1982), adsorption (Kutluay et al,2004), Advanced Oxidation based fenton process (Kurt et al., 2006), conventional chemical coagulation and electrochemical treatment process (Gohary et al., Dovletoglou et al, 2002). Although WAO technology has shown its great potential for treating different variteties of waste streams containing pollutants, It is usually an expensive process when used to achieve complete oxidation of all organic material (Wilhelmi & Knopp, 1979). Maintaining the typical operating pressure and temperature of a WAO is energy consuming, implying that it is a relatively costly process in comparison with other conventional wastewater treatment methods (Lin & Ho, 1996). Additionally, among the compounds that have been catalogued as readily oxidizable by means of WAO are aliphatic and aromatic compounds, which do not contain halogenated functional groups. Compounds containing halogen and nitro functional groups have been found to be difficult to degrade by this method (Scott, 1997).

All the advanced oxidation methods suffer from high operating cost (Idris et al., 2003). Chemical coagulation is becoming less acceptable because of the higher costs associated with chemical treatments (Norulaini et al., 2001). In recent years, however, electro-coagulation is becoming an alternative for wastewater treatment and starting to replace conventional processes, because many industrial processes produce toxic wastewater, which are not easily biodegradable and require costly physical or physic-chemicals pretreatments (Pulgarin et al, 1994).

Electrocoagualtion process removes pollutants principally by coagulation, adsorption, precipitation and flotation (Canizares et al., 2005; Carmona et al., 2006). Electro coagulation has been successfully used to treat wastewaters from olive mill (UN et al., 2006; Adhoum et al., 2004), surfactant (Zor et al., 2006), food process (Diaz et al., 2006), dairy (Sengil et al., 2006), Pulp and paper mill (Mahesh et al., 2006), poultry slaughterhouse (Kobya et al., 2006), tannery (Murugananthan et al., 2004), textile (Kobya et al., 2007). However, there is a lack of research dealing with EC treatment of industrial paint wastewater in literature where only few references dealing only with simulated paint wastewater were found at the time of undertaking this research. This fact, therefore, had been taken into consideration and decided to investigate this technology on real industrial paint wastewater. The samples used in this study had been collected from a paint factory located in Dammam Second Industrial City.

The main objective of this study is to investigate the effectiveness of treating of paint industrial wastewater using the electro-coagulation process. The study also

aims to investigate the optimum operation parameters namely; the current density and contact time to remove the organic and inorganic compounds, Turbidity and Total Suspend Solid (TSS).

CHAPTER 2

LITERATURE REVIEW

2.1 PAINT INDUSTRY WASTEWATER

Paint is generally considered as a mixture of pigment, binder, solvent and additives. Paint classification can be made based on different criteria; one convenient method is to classify paints based on their primary solvent for waste reduction and disposal. Using this approach, paints can be classified as water based, organic solvent based or powder (dry) and without solvent (Bahadir et al., 2007).

The main source of wastewater in any paint industry is the manufacturing plant water-based paint. Usually high volume of wastewater is generated during washing activities at paint industrial units in the water-based paint manufacturing area and water-based resin manufacturing area and lead-chromate pigment manufacturing process zone. The environmental challenge of the paint industry is associated with the generated wastewater that contains high concentration of organic compounds and heavy metals. The effluent from paint wastewater contains an Absorbable Organic Halogen. Some of the organic halogen compounds are highly toxic, carcinogenic, bio-accumulative and persistent (Fick, 1989).

Level of pollution varies from industry to industry, depending mainly on the types of process and the size of the industry. The concentration of various elements present in the

wastewater collected from local paint manufacturing plant located in industrial city of Riyadh, Saudi Arabia was measured by using Laser Induced Breakdown Spectroscopy (LIBS) system. The results are presented in the Table 2.1 below. Additionally, wastewater samples were collected from a paint factory located in Malaysia and analyzed against pH, Conductivity, Turbidity, COD, BOD, TKN, Total phosphorus, Chloride and Sulphate. The results are shown in Table 2-2.

Table 2-1: Elements detected in wastewater collected from a paint factory located in Riyadh (Gondal et al., 2006)

Elements detected in wastewater	Wave length (nm)[a]	Comparison of LIBS and ICP and Relative Accuracy (RA)			Standard deviation (S.D.)LIBS	Limit of detection (LOD) of LIBS (mg/kg)	Maximum permissible safe limits (mg/kg)[b]
		LIBS (mg/Kg)	ICP (mg/Kg)	RA			
Al	394.4	133.2	129.0	0.03	1.09	12	30
Ba	553.54	119.2	114.0	0.04	1.12	14	20
Ca	393.37	301.7	293.0	0.03	1.16	12	-
Cr	428.9	3.70	2.46	0.56	0.99	2	1.0
Fe	567.9	119.7	115.0	0.04	0.71	10	25
Cu	324	3.20	2.65	0.26	0.95	2	1.2
Mg	518.29	199.6	192.0	0.04	0.75	3	-
K	404.72	28.0	25.30	0.11	1.33	4	-
Na	588.9	172.6	166.0	0.04	0.92	5	1000
Ni	352.4	1.20	0.51	0.60	1.16	0.2	2.5
P	255.3	237.9	230.0	0.03	1.23	4	50
Pb	280.2	6.19	5.90	0.07	0.99	3	0.5
S	547.9	71.6	67.60	0.06	1.12	7	800 for

Elements detected in wastewater	Wave length (nm)[a]	Comparison of LIBS and ICP and Relative Accuracy (RA)			Standard deviation (S.D.)LIBS	Limit of detection (LOD)	Maximum permissible safe limits sulphate
Si	250.69	35.2	32.60	0.08	1.43	10	-
Sr	460.73	4.10	3.20	0.32	1.60	2	-
Ti	445.7	42.05	39.30	0.07	1.43	10	-
Zn	334.5	20.1	18.3	0.11	1.12	5	10
Zr	487.2	12.30	9.25	0.34	1.73	4	-

a:Reference for wavelength and NIST database

b:Environmental Regulation Standards for Saudi Industries set by Royal Commission Jubail, Saudi Arabia

Table 2-2: Characteristics of paint wastewater collected from a paint facility located in Malaysia (Abo Alhassan, 2006)

Parameters	Unit	Concentration		
		Minimum	Maximum	Average
pH	-	6.70	7.80	7.35
Conductivity	ms/cm	2.05	2.68	2.33
Turbidity	NTU	1.09	56.00	26.83
COD	mg/l	4438.19	25105.69	16342.32
BOD	mg/l	960.00	1968.00	1465.20
TKN	mg/l	50.03	490.30	199.73
Total phosphorus	mg/l	1.42	16.08	7.46
Chloride	mg/l	177.65	355.00	266.33
Sulphate	mg/l	55.35	5768.87	2389.01

2.2 THEORIES OF ELECTRO-CHEMICAL TREATMENT

Electrochemical applications using many kinds of electrode materials such as aluminum, iron, graphite, diamond and platinum have been a focus of research by a number of groups during the last decades. The electrochemical approach has been adopted successfully to develop various environmental applications mainly in water and wastewater treatment. In this research, stainless steel electrodes were used because they are cheaper, more effective and readily available (Matteson et al., 1995; Abuzaid et al., 1998; Bukhari et al., 1999; Holt et al., 2005).

2.2.1 Electrocoagulation (EC)

Electrocoagulation (EC) process can be applied to a broad range of water and wastewater treatment systems. EC has been successfully employed in removing metals, suspended particles, clay minerals, organic dyes, and oil and greases from a variety of industrial effluents (Mollah et al, 2004). In this process, a potential is applied to the metal anodes, typically fabricated from either iron or aluminum. Because of its broad applicability, it has been used also for groundwater and surface water remediation at several sites (Joffe & Knieper, 2000). Electrochemical methods offer some advantages over traditional chemical treatment: less coagulant ion is required, less sludge is formed and electrocoagualtion equipment is very compacting thus suitable for installation where the available space is limited. Furthermore, the convenience of dosing control only by adjusting currents makes automation quite easy (Jiang et al., 2002; Kumar et al., 2004; Diaz et al., 2003)

The process is characterized by ease of operation, reduced production of sludge, and no need to handle chemicals. According to Rajeshwar & Ibanez (1997) EC process can replace conventional chemical coagulation. EC requires little modifications to make the current treatment plants more efficient and eliminate the problems associated with chemical coagulation.

In EC process, the coagulation ions are produces in situ and it involves three successive stages namely, Formation of coagulants by electrolytic oxidation of the sacrificial electrode, destabilization of the contaminants particulate suspension and breaking of emulsions and aggregation of the destabilized phases to form flocs. The destabilization mechanism of the contaminants, particulate suspension, and breaking of emulsions has been reported by Mollah (2004) as follows:

- Compression of the diffuse double layer around the charged species by the interactions of ions generated by oxidation of the sacrificial anode.
- Charge neutralization of the ionic species present in wastewater by counter ions produced by the electrochemical dissolution of the sacrificial anode. These counter ions reduce the electrostatic interparticle repulsion to the extent that the van der Waals attraction predominates, thus causing coagulation. A zero net charge results in the process.
- Floc formation; the floc formed as a result of coagulation creates a sludge blanket that entraps and bridges colloidal particles still remaining in the aqueous medium.

When stainless steel is used as an anode, upon oxidation in an electrolytic system, it produces iron hydroxide, Fe (OH)n, where n is either equal to 2 or 3. Two mechanisms for the production of the iron hydroxides have been proposed (Mollah et al., 2001; Holt et al., 1991; Chen, 2004).

1. Mechanism 1

• Anode: $4Fe \rightarrow 4Fe^{2+} + 8e^{-}$ (1)

$4Fe^{2+} + 10H_2O + O_2 \rightarrow 4Fe(OH)_3 + 8H^{+}$ (2)

• Cathode: $8H^{+} + 8e^{-} \rightarrow 4H_2$ (3)

2. Mechanism 2

• Anode: $Fe \rightarrow Fe^{2+} + 2e^{-}$ (4)

$Fe^{2+} + 2OH^{-} \rightarrow Fe(OH)_2$ (5)

• Cathode: $2H_2O + 2e^{-} \rightarrow H_2 + 2OH^{-}$ (6)

Ferric ions generated by electrochemical oxidation of iron electrode may form monomeric ions, $Fe(OH)_3$ and polymeric hydroxy complexes, namely: $Fe(H_2O)_6^{3+}$, $Fe(H_2O)_5(OH)^{2+}$, $Fe(H_2O)_4(OH)_2^{+}$, $Fe_2(H_2O)_8(OH)_2^{4+}$ and $Fe_2(H_2O)_6(OH)_4^{4+}$ depending on the pH of the aqueous medium which transform finally into $Fe(OH)_3$ at pH around 8 (Kobya et al., 2006). Figure (2-1) shows schematic diagram of a bench scale two electrode electrocoagulation cell.

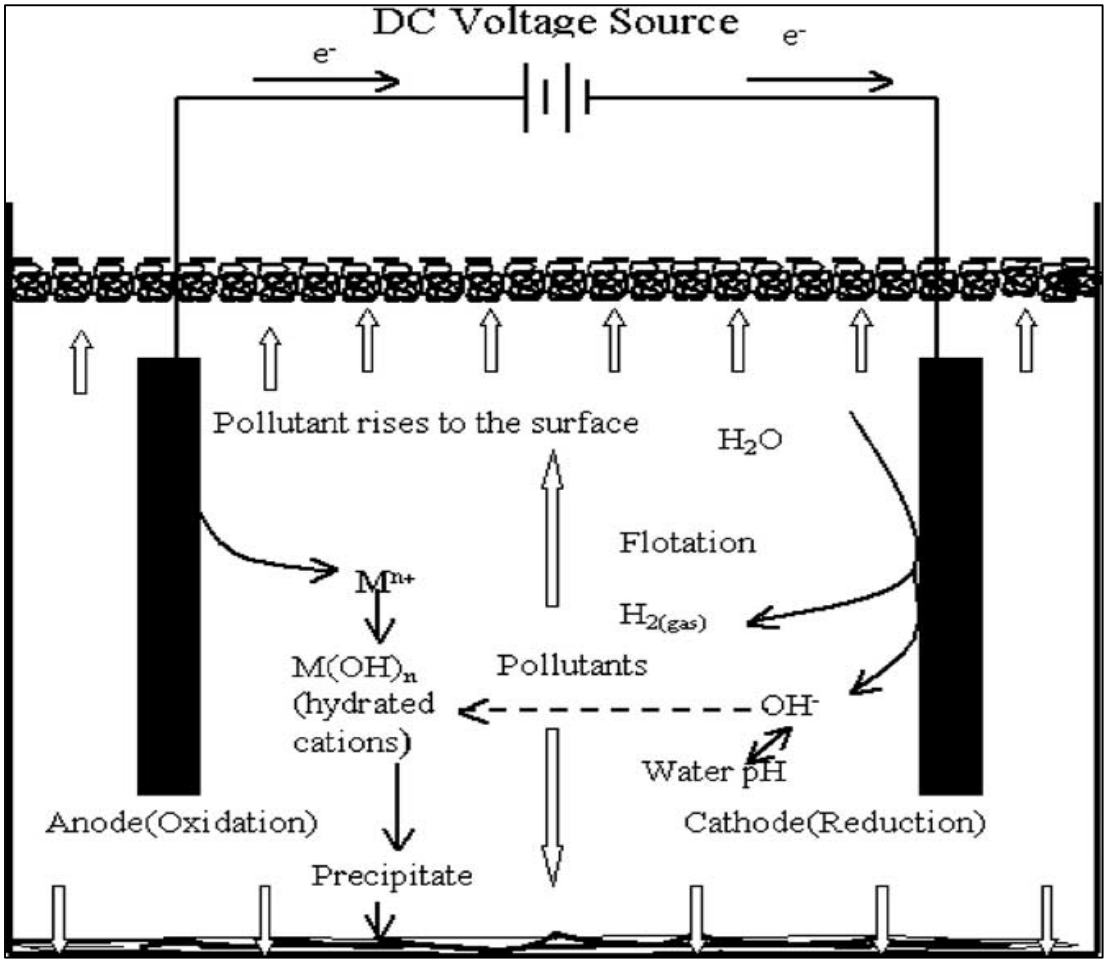

Figure 2-1.Schematic diagram of bench scale two electrode electrocoagualtion cell

EC needs simple equipments, designable for virtually any size. It is cost-effective, and easily operable. The start-up and operating costs are relatively low. It requires low maintenance cost with no moving parts. Since practically no chemical addition is required in this process, it brings minimum chance of secondary pollution. It needs low current, and it can be run even by green processes, such as, solar, windmills and fuel cells. Electrocoagulation process can effectively destabilize small colloidal particles. Gas bubbles produced during electrolysis can enhance flotation. It removes the smallest colloidal particles efficiently in compared with the conventional chemical and biological techniques, because the smallest charged particles have greater probability of being coagulated by the electric field that sets them in motion (Sayinera et al., 2008).

2.2.2 Electroxidation (EO)

Generally, oxidation of organic matter by electrochemical treatment can be classified as direct oxidation and indirect oxidation. Direct oxidation occurs at anodes by generating physically adsorbed “active oxygen” (adsorbed hydroxyl radicals, .OH). This process is usually called anodic oxidation. The mechanism of oxidation of organic matter at oxide anode (MO_x) was suggested by Comninellis (1994). Water is electrolyzed by anodic catalysis to produce adsorbed hydroxyl radicals, given as Eq. 7:

$$H_2O + MO_x \rightarrow MO_x[\cdot OH] + H^+ + e^- \quad (7)$$

The adsorbed hydroxyl radicals may form chemisorbed active oxygen, as shown in Eq. 8:

$$MO_x[\cdot OH] \rightarrow MO_{x+1} + H^+ + e^- \quad (8)$$

Indirect electrooxidation involves the use of chlorine and hypochlorite generated anodically to destroy the pollutants (Szpyrkowicz, 2001). Eq. 9 shows the formation of hypochlorite in a solution containing chlorides.

$$H_2O + Cl^- \rightarrow HOCl + H^+ + 2e^- \quad (9)$$

In addition, high voltage pulse can lead to the formation of a strong electric field, which produces free radicals and molecules, such as .OH, .O, H^+ and H_2O_2, etc. (Sun, 2001).

$$H_2O \rightarrow .OH, .O, {}^+H, H_2O_2 \quad (11)$$

Organic matter (R) included in wastewater is oxidized by hydroxyl radicals (Comninellis, 1994), and the reactions are given in Eq. 12, 13 & 14.

$$R + MO_x[{}^{\cdot}OH] \rightarrow MO_x + CO_2 + zH^+ + ze^- \quad (12)$$

$$MO_{x+1} + R \rightarrow MO_x + RO \quad (13)$$

$$R + HOCl \rightarrow product + Cl^- \quad (14)$$

2.3 ELECTROCHEMICAL PROCESS IN PAINT WASTEWATER TEREATMENT

Selection of an appropriate treatment technology basically depends on demand and supply of inhabitants, geographical situation, meteorological conditions, economic welfare, industrialization, development, and finally on the discharge limits of the country. The most widely preferred and applied treatment system for dairy and dairy products wastewater is any of the biological ones (Schwarzenbeck et al., 2004; Strydom et al., 1995). However, electrochemical treatment has proved and holds significant importance in treating such wastewaters. Few reports have been published in the scientific literature for treating the paint wastewater with electrochemical process in recent years (Bahadir et al., 2007) at the time of undertaking this research. This section presented articles that showed the efficiency of electrochemical process in treating the paint wastewater and on similar characteristics of the paint wastewater.

2.3.1 Electrochemical Treatment of Colloidal Wastewater

Electrocoagulation of groundwater, using iron electrodes, was performed by Abuzaid et al. (2002) to observe the separation of colloids by adding bentonite in the water. The experimental work was designed to investigate the effect of current input, contact time, final water pH and electrolyte concentration on the turbidity removal efficiency of the cell. Optimum values for the above said parameters were shown for the maximum removal of turbidity values. The highest turbidity removal efficiency of 95% was achieved at a current of 1 A and a contact time of 5 min. An optimal residual turbidity of 1.6 NTU was found at a contact time of 10 min and a calculated amount of iron generated

of 86.8 mg/l. It was seen that reduction of the current from 1 to 0.5 A and increase of contact time from 5 to 10 min caused the residual turbidity to drop from 4.0 to 1.6 NTU. Use of 1 g/l NaCl as an electrolyte also showed that similar turbidity removals can be achieved at a much shorter time of 2 min. The influence of the pH increase due to the voltage induced hydrogen evolution on the coagulation efficiency was studied as well. While the solution final pH increased with the increase in current and contact time, it was found to decrease with the increase in sodium chloride concentration. This trend is attributed to two reasons; first, the increase in NaCl concentration increases the conductivity of the solution which reduces the voltage needed to have a certain current. Voltage reduction would reduce the hydrogen evolution, which is responsible for the increase in pH. Second, the increase in NaCl concentration increases the amount of chloride ions, which can be electrically converted to chlorine gas. The increase in chlorine gas production increases the concentration of hypochloric acid in the test water. This tends to reduce the solution final pH.

Canizares et al. (2005) studied the effect of the electrocoagulation process of synthetic colloid-polluted waste, in a continuous single-flow electrochemical cell equipped with aluminum electrodes. Study showed that removals of turbidity higher than 75% can be obtained with low currents. The researcher found that the more important variables in the process are the aluminum concentration generated in the system and the pH. The amount of aluminum generated in the process was always over the expected value, and is strongly influenced by the pH and the current density, because both chemical and electrochemical dissolution occur in the electrochemical cell. For acid pHs, small concentrations of

aluminum achieved good coagulation efficiencies (80% removal of turbidity), while for alkaline pHs neither high nor low concentrations of aluminum yielded good coagulation results. It was observed that the removal percentage increases with the increase in kaolin concentration and reaches a constant value for kaolin concentration higher than 1 g/dm^3. The behavior of the experimental mechanism was depicted by two coagulation mechanisms: at acid pHs, the neutralization of the superficial charge of the clays and at neutral pHs (and also at high concentrations of aluminum), the enmeshment of the kaolin particles into a sweep floc.

Larue et al. (2003) studied coagulation of fine disperse latex particles of suspensions by using iron electrodes. The goal of their work was to enhance suspension clarification, promote sedimentation and improve their filterability. Two kinds of iron dosing were studied; by directly adding iron chloride or iron sulphate to suspensions and by electrolytic decomposition of iron electrodes (EC). Optimum arrangements of the operating conditions in EC (pH, residence time, conductivity, current density) were found. The adjustment of conductivity around 0.6 S/m was found to be appropriate to reduce energy consumption without affecting EC performances. Conductivity and pH were adjusted to 0.6 S/m and 7.5, respectively. At these values, the energy consumption increased significantly and proportionally with the increase of current density. From 4.4 to 8.8 A/dm^2, EC performance clearly declined. For EC-treated suspensions, the subsequent liquid-solid separation by sedimentation or filtration was actually improved. Large settling flocs appeared at neutral or basic pH. EC produced a lower sediment amount. The specific resistance of the cake formed by filtration of EC-treated

suspensions became lower than the one obtained with chemicals. The cakes formed by filtration of EC-treated suspensions display a lower coefficient of compressibility. Therefore, the increase in filtering pressure can be useful to improve the filtration kinetics.

A study was conducted by Mansoor Jehangir, 2006 to assess the potential of electrooxidation and electrocoagulation on the removal of organic matter from simulated dairy industry wastewater. The electrochemical process was carried out in a batch reactor equipped with iron electrodes. The effects of current, contact time, iron production, electrolyte concentration and pH were investigated and optimum operating range for each parameter was experimentally determined. The results obtained were useful to clarify the mechanism that is involved in the electrochemical treatment of this kind of wastewater. Comparing the electrochemical results with the results obtained from conventional coagulation (using $FeCl_3$) and filtration, it was found that electrocoagulation was the only governing mechanism in this research for the removal of COD and turbidity. The current density had a significant effect on the kinetics of the wastewater treatment for both COD and turbidity removal efficiencies. After attaining maximum removal efficiency of 67-69%, for all concentrations under all currents, COD abatement remained the same for higher contact times. 0.4 A current at 10 min of contact time, 0.8 A current at 10 min of contact time & 0.4 A current at 20 min of contact time are the optimum ranges determined for obtaining maximum removal efficiency at the initial COD concentrations of 2500 ppm, 5000 ppm & 10000 ppm, respectively. In terms of iron dosage; 69.5, 138.9 & 138.9 mg/l were required to obtain maximum removal for the three initial

concentrations. The change in the removal efficiency after increasing the pH and conductivity (by using NaCl) was also analyzed. Increase in pH and conductivity did not show any significant change in the removal efficiency of the process.

2.3.2 Electrochemical Treatment of Paint Wastewater

As mentioned earlier, at the time of undertaking this research, there was a lack of research dealing with electrochemical treatment of paint waste in the literature (Bahadir et al., 2007). The studies found that are dealing with paint wastewater are presented below.

Bahadir et al, 2009 had investigated the efficiency of electrochemical treatment of industrial water-based paint wastewater in a continuous tubular reactor with the presence of NaCl electrolyte on carbon anode and stainless steel cathode. The synthetic paint wastewater was prepared with 46,14 ml acrylic copolymer based white primer and 4.62 ml water-based blue colorant in a solution added up to 1L using double distilled water which corresponds to 4.4 %(w/v) mixture. The characteristics of simulated water-based paint wastewater had COD, pH and Total Suspend Solid (TSS) values of 7863 mg/l, 7.84 and 3021 mg/l, respectively, with 4.4% (w/v) of total solid content. The effects of residence time on chemical oxygen demand (COD), color and turbidity removals and pH change was studied at 30 ◦C, 35 g/L electrolyte and 7496 mg/L COD feed concentrations with 66.8 mA/cm^2 current density. The optimum residence time in the reactor was determined as 6 h for a cost driven approach, enabling COD, color and turbidity removal as 44.3%, 86.2% and 87.1%, respectively, and a discharge pH value of 7.33. At 6 h of

residence, 42kWh energy was consumed per kg COD removed maintaining a mass transfer coefficient value of 3.62×10^{-6} m/s. In all runs, the polymer/water emulsion always broke into insoluble solid particles during the electrochemical treatment, which eventually precipitated.

Bahadir et al, 2007 had carried out another study to investigate the efficiency of electrochemical treatment of a simulated water-based paint. The treatment was investigated batch wise in the presence of NaCl electrolyte with carbon electrode. The water – based paint wastewater was synthetically prepared from industrial components for the standardization of the wastewater throughout the study. The electrochemical reactor system was used batch-wise in all runs. The reactor was made of Pyrex® glass having a net volume of 600 mL with a heating/cooling coil around. Three pairs of carbon electrodes (OD = 12 mm) were used as anode and cathode, and placed 1.5 cm apart on a Plexiglas® reactor cover. A glass stirrer with a single 4 cm×1.5 cm rectangular paddle was driven with a Heidolph-RZR 1 model mixer at 575 rpm. The reaction temperature was monitored with a glass thermometer immersed and controlled with circulating water recycled from a temperature controlled water bath (New Brunswick, Model G-86). The current was applied by a constant voltage/current controlled dc power source (NETES Model NPS-1810D). Synthetic paint wastewater was loaded into the reactor and the reaction under predetermined conditions started with the application of specified voltage and continuous agitation. At appropriate time intervals, samples of 5mL were taken from the reactor and analyzed to determine the chemical oxygen demand, color, turbidity and pH.

The electrochemical treatment conditions were optimized using response surface methodology where potential difference, reaction temperature and electrolyte concentration were to be minimized while chemical oxygen demand (COD), color and turbidity removal percents and initial COD removal rate were maximized at 100% pollution load. The optimum conditions were satisfied at 35 g/L external electrolyte concentration, 30 ◦C reaction temperature and 8V potential difference (64.37 mA/cm^2 current density) realizing 51.8% COD and complete color and turbidity removals, and 3010.74 mg/L h initial COD removal rate. According to these results, the electrochemical method could be a strong alternative to conventional physicochemical methods for the treatment of water-based paint wastewater with further research.

CHAPTER 3

RESEARCH OBJECTIVES

The main objective of this research was to assess the potential of electrocoagulation on the removal of organic matter and suspended solid from the paint industry wastewater. The specific objectives are:

- To investigate the effect of current density and the contact time on the removal efficiency of COD, TSS and Turbidity.
- To assess the quality of the treated wastewater in terms of organic (COD) and inorganic metals (Al, Ba, Cd, As, Hg, Cr, Ni, Pb and Zn).
- To determine the energy consumption used for treating the paint wastewater.
- To investigate the effect of iron coagulant produced during electrocoagulation, on the reduction of TSS and Turbidity.
- Investigating the extent of electrooxidaiton.
- To study the effect of electrolyte concentration on the removal of COD, turbidity and TSS.

CHAPTER 4

MATERIALS AND METHODS

This chapter presents the apparatus, materials, methods and analysis used in this study to carry out the laboratory investigations required to achieve the outlined objectives of this research.

4.1 PAINT WASTEWATER

The wastewater samples used throughout this study were collected from a septic tank of a paint factory located in Dammam second industrial city. The factory is equipped with one septic tank (underground tank) where it receives only the wastewater generated from the processes related to the production of paint. To undertake the experiments under the same conditions, 60 liters of wastewater were collected and stored in a refrigerator at 4 degree Celsius.

4.2 EXPERIMENTAL SETUP

The batch experimental setup is shown in figures 4-1. The Electrochemical setup consists of an electrochemical cell (600 ml glass beaker with pyrex strips attached as baffles), a D.C. power supply (Hampden, USA), a rheostat (Engield-Middlesex, UK) to keep the current invariant and a pair of stainless steel electrodes (each with a dimension of 10 cm × 4 cm) separated by a spacing of 3 cm and dipped in the wastewater with a total effective submerged area of 45.6 cm^2. In addition, an Ammeter (Hampden, USA), a magnetic stirrer, a magnetic stirrer controller and a stand for holding electrodes were

used. A switch was used to change the polarity of electrodes to reduce passivation phenomenon that usually occurs at the cathode and retards oxidation and reduction reactions. Other items used for COD testing, were according to the standard methods 5220C [Standard Methods (APHA, AWWA, WEF, 1998)].

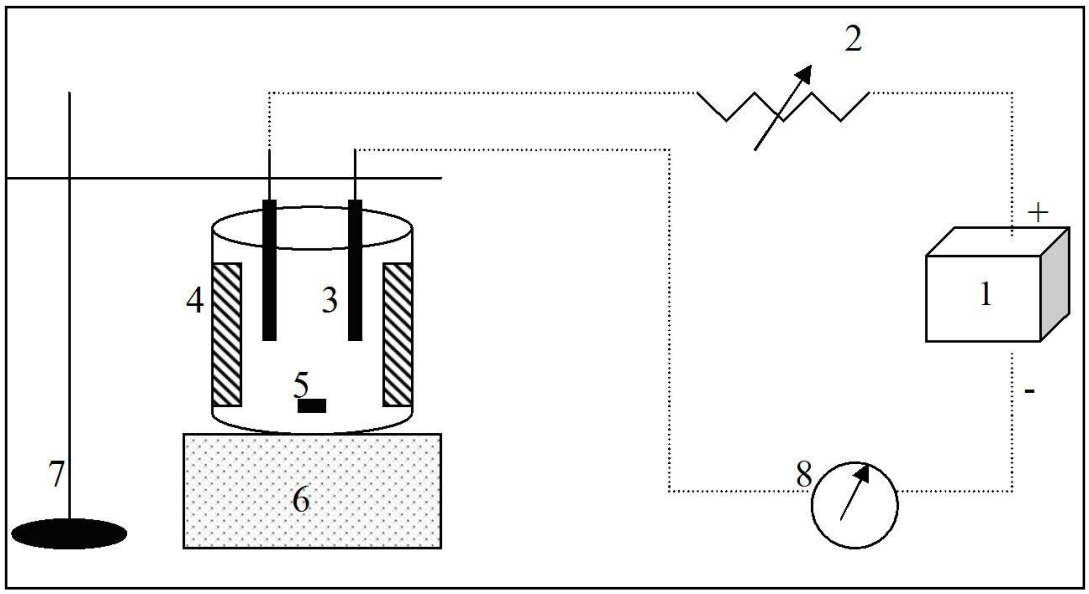

Figure 4-1.Schematic setup of EC unit

1) D.C power supply
2) Variable resistance
3) Stainless steel electrodes
4) Glass breaker with baffles
5) Magnetic bar
6) Magnetic stirrer
7) Iron stand for electrodes
8) Ammeter

4.3 METHODOLOGY

All experiments were conducted under room temperature in batch modes. Before running the experiments, pH, turbidity, conductivity, TSS, heavy metals and COD tests were performed to obtain the initial values of paint wastewater samples. At the beginning of a run, a wastewater sample was taken in a 600 ml beaker and placed on the magnetic stirrer for thorough mixing. Stainless steel electrodes were dipped into the sample wastewater. In certain experiments, various amounts of electrolyte (NaCl) were added to the solution to investigate the effect of conductivity on the removal mechanism.

The aforementioned parameters were investigated under the effects of different currents (0.2, 0.4, 0.6, 0.8 and 1.0 A).Current was passed through the beaker for different contact times (10, 20, 30, 40 and 60 min). The reaction was timed to start when the DC power supply was switched on. To reduce the effect of passivation, electrodes were cleaned after each run and changed after every 5 runs.

After passing each current for certain contact time, sample was taken in another beaker and placed under a jar test equipment for flocculation of particles with in-situ generated coagulant produced during the passage of current. Under jar test apparatus, samples were mixed for flocculation for 20 min by setting the speed of the paddles at 40 rpm. After the mixing stage, samples were left undisturbed for 30 min for the flocs to settle. Supernatant was then taken for analyses.

The design of experiments of this study is divided into two phases. In both phases, the analyses of the wastewater were carried out against COD, TSS, Turbidity, Ba, Cr, Ni, Pb, Hg, As, Cd and Zn.

The first phase comprises of thirty (30) experiments. Different sets of current densities and contact times were used. The current densities ranged from 0.25 mA/cm^2 to 25 mA/cm^2 whereas the ranges of the contact times were between 0 to 60 minutes. During this phase, the electrolyte solution was not added to benefit from the conductivity that is originally available in the water used in the process.

The second phase consists of eighteen (18) experiments. In this phase, the optimum current density obtained from the first phase shall be performed along with different concentrations of Sodium Chloride (NaCl). Table 4-1 provides the experimental design adapted for this study. In order to elucidate the governing removal mechanism in the overall removal of the contaminants, conventional coagulation was done by using ferric chloride.

Table 4-1: Experimental design adapted for this study.

Experimental Group	Current Density mA/cm^2	Contact Time (min)	NaCl Conc. (mg/l)
CURRENT DENSITY AND CONTACT TIME INVESTIGATION			
1-6	1.25	0, 10, 20, 30, 45, and 60	NA
6-12	6.25	0, 10, 20, 30, 45, and 60	NA
12-18	12.5	0, 10, 20, 30, 45, and 60	NA
18-24	18.75	0, 10, 20, 30, 45, and 60	NA
24-30	25	0, 10, 20, 30, 45, and 60	NA
INVESTIGATION OF PROCESS EFFECT ON COD, TSS, TURBIDIT AND HEAVY METALS AT THE OPTIMUM OPERATING PARAMETER			
30-36	Optimum	0, 10, 20, 30, 45, and 60	2000
36-42	Optimum	0, 10, 20, 30, 45, and 60	3000
42-48	Optimum	0,10,20,30,45 and 60	4000

NA: Not Added

4.4 ANALYTICAL PROCEDURES

For all experiments the physiochemical parameters were analyzed by the methods and apparatus mentioned below.

4.1.1 pH

Jenway model 3345 Ion meter was used for determining the pH of each sample before and after electrocoagulation.

4.1.2 Turbidity

A HACH-2100P Turbiditymeter was used to determine the turbidity of each sample before and after electrocoagulation.

4.1.3 Conductivity

A YSI Model 35 Conductance meter was used to measure the conductivity of each sample in μS/cm, before and after conducting the experiments.

4.1.4 Jar Test

PHIPPS & BIRD Stirrer Model 7790-400 was used to conduct jar test for coagulation and flocculation of each sample after electrocoagulation in EC unit.

4.1.5 COD Test

The COD test was carried out before and after electrocoagulation of each sample according to the Standard Methods (APHA, AWWA, WEF, 1998); 5220C, Closed Reflux Titrimetric method for COD determination.

4.4.6 Inductively Coupled Plasma Mass Spectrometry (ICPMS)

A 7500 cx ICPMS was used to determine the heavy metals of each sample before and after the electrocoagualtion

4.4.7 Gas Chromatograph –Mass Spectrophotometry (GC-MS)

Agilent's 6890N GC/MS analyzer was used for the analysis of the organic constituents before and after the electrocoagualtion treatment.

CHAPTER 5

RESULTS & DISCUSSIONS

5.1 WASTEWATER CHARACTERIZATION

The samples collected from the source had been analyzed to determine their physicochemical characteristics, namely pH, conductivity, TCOD, DCOD, PCOD, TSS, turbidity and heavy metals. In addition, further investigations had been carried out to determine the organic constituents before and after the treatment. Table 5-1 provides the physicochemical characteristics of the raw samples used in this study whereas Table 5-2 presents the constituents of the organic compounds found in the sample.

It can be observed form the Tables below that the most of COD, nearly 84.32%, is in the particulate form. Additionally, the relatively high conductivity in the samples is advantageous to the electrochemical treatment since it will eliminate the need to add an electrolyte that is necessary to facilitate the passage of the current in wastewater. However, investigations of adding different concentrations of NaCl were carried out. The concentrations of heavy metals in the samples used through the study were very low.

Table 5-1: Physicochemical characteristics of the paint industrial wastewater used in the study

Parameter	Concentration
pH	7.4
Total COD (mg/l)	19136
Soluble COD (mg/l)	3000
Particulate COD (mg/l)	16136
TSS (mg/l)	6500
Turbidity (NTU)	13000
Conductivity (Ms/cm.)	1300
Ba (mg/l)	6.6
Cr (mg/l)	0.012
Ni (mg/l)	0.011
Zn (mg/l)	0.475
As (mg/l)	N.D
Cd (mg/l)	N.D
Hg (mg/l)	N.D
Pb (mg/l)	N.D

Table 5-2: Organic constituents identified in raw samples

Sr.No	Retention Time	Compound Name
1	10.9	2-Propanol, 1-methoxy
2	11.7	C_7H_{16}
3	12.4	1,2-Ethanediol
4	13.1	Propyl glycol
5	14.7	C_8H_{18}
6	16.4	1-Mehoxy-2-propyl acetate
7	17.3	C_9H_{20}
8	19.7	$C_{10}H_{22}$
9	21.9	$C_{11}H_{24}$
10	23.2	1,3-Pentanediol-2,2,4-Trimethy
11	23.9	C_{12} H_{26}
12	26	$C_{13}H_{28}$
13	27.4	Propanoic acid -2-methyl-3-hydroxy-2,4-TMPE

5.2 EFFECT OF CURRENT AND CONTACT TIME

The effects of current density and contact time were investigated on COD, T.S.S, and turbidity removal efficiencies for the industrial water-based paint wastewater. Additionally, the quality of treated wastewater in terms of organics (COD) and inorganic parameters were assessed. This section presents the results and the discussions obtained from conducting the experiments.

Figure 5-1 shows the relationship between the COD removal efficiency and contact time for the range of currents used in this study. The figure shows for the current 0.2 A that the removal efficiency has increased from 6% at 10 min to 19% at 20 min of contact time. Further increase in contact time up to 30 min resulted in slight increase of the removal efficiency to 21%. Beyond the contact time of 30 min, removal efficiency continued to increase as a function of time. For current 0.4 A the removal efficiency has increased from 16% at 10 min to 33% at 20 min. after 20 min of contact time, the removal efficiency was almost stable as a function of time. For the 0.6 A, the removal efficiency has increased from 37% at 10 min to 75% at 20 min of contact time. Further increase in contact time up to 30 min resulted in slight increase of the removal efficiency. However, beyond the contact time of 30 min, removal efficiency continued to increase as a function of time. For 0.8 A and 1.0 A, as the contact time increased from 10 to 60 min removal efficiencies increased from 27% to 88% and from 18% to 72% as a function of time.

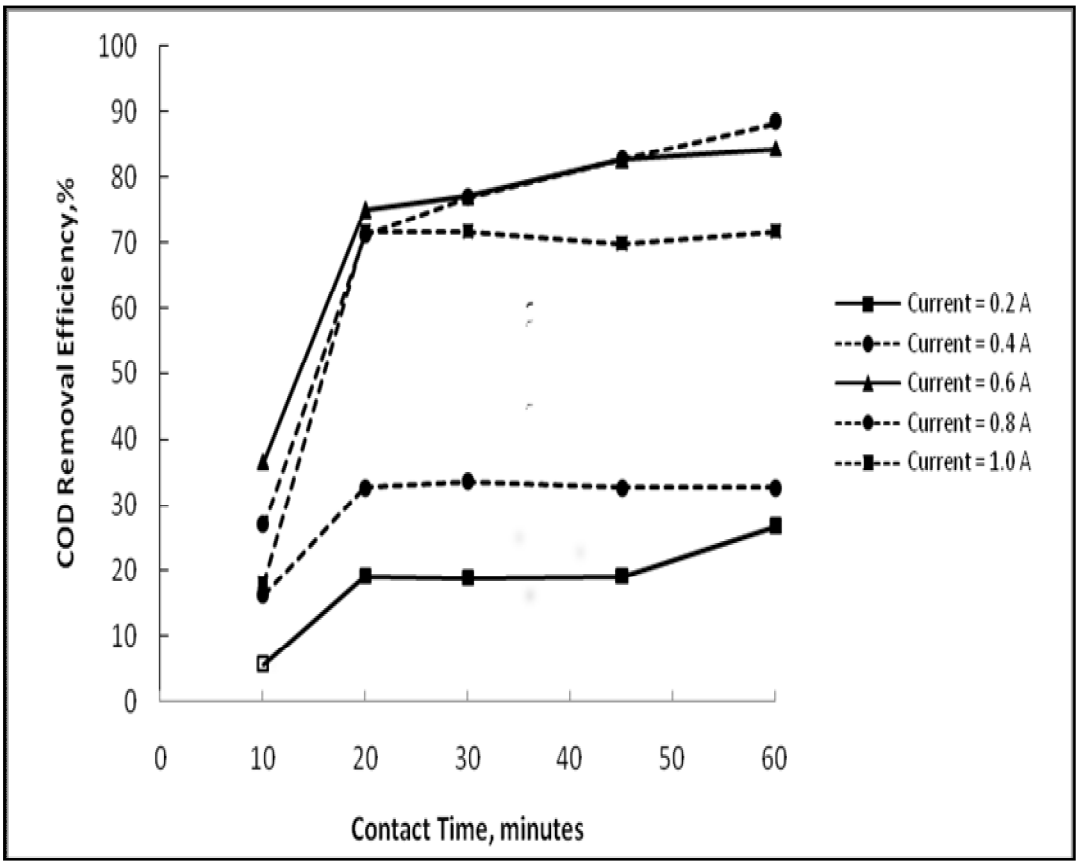

Figure 5-1: The relationship between COD removal efficiency and contact time for the range of current used in this study.

As observed from the results of physicochemical characteristics, the major COD in the paint wastewater was in the particulate form. The removal of COD could be attributed to the mechanisms responsible for the removal of T.S.S, which are sweep –floc and charge neutralization. Figure 5.2 shows the same removal trend in terms of residual COD values. The lowest residual COD concentration was achieved at current 0.8 A for a contact time of 60 minutes where the value was 2208 mg/l . This value is above 1500 mg/l which is the value of the pretreatment guidelines for discharge to central treatment facilities prescribed in General Environmental Regulation (GER) of Presidency of Meteorology and Environment (PME).

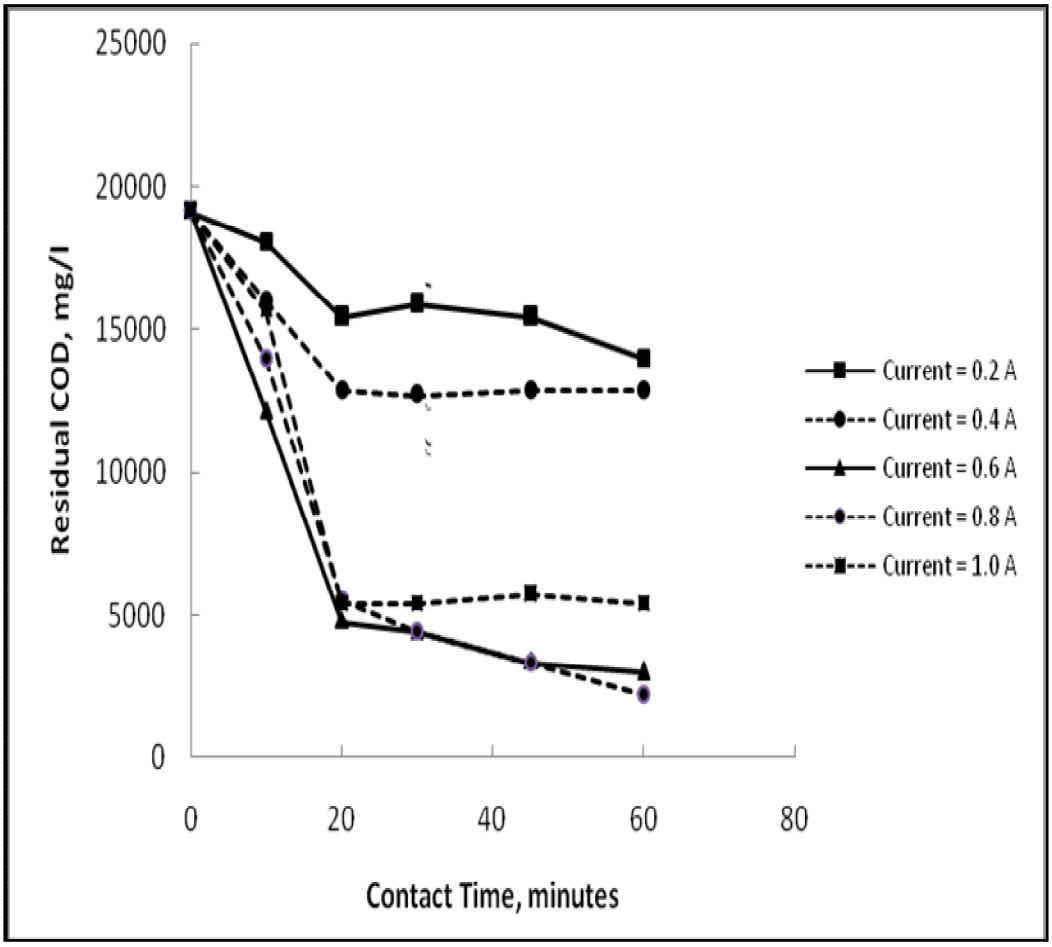

Figure 5-2: The relationship between the residual COD and contact time for the range of currents used in this study.

The relationship between the TSS removal efficiency and contact time for the range of currents used is depicted in Figure 5-3. The Figure shows that as the contact time increased from 10 to 60 min, removal efficiencies increased from 23% to 64% and from 25% to 67% for the currents of 0.2 A and 0.4 A as function of time, respectively. For the 0.6 A, 0.8 A and 1 A, the removal efficiencies increased up to 20 min of contact time and beyond that no further increase is observed. The highest removal efficiencies of 98%, 99% and 98% for 0.6A, 0.8 A and 1 A current occurred at a contact time of 30 min, respectively. Figure 5.4 shows the same removal trend in terms of residual TSS values. All the values obtained at 20 min of contact time and beyond that were in compliance with the direct discharge standard and the pre-treatment guidelines of GER of PME for the TSS which is 2000 mg/l.

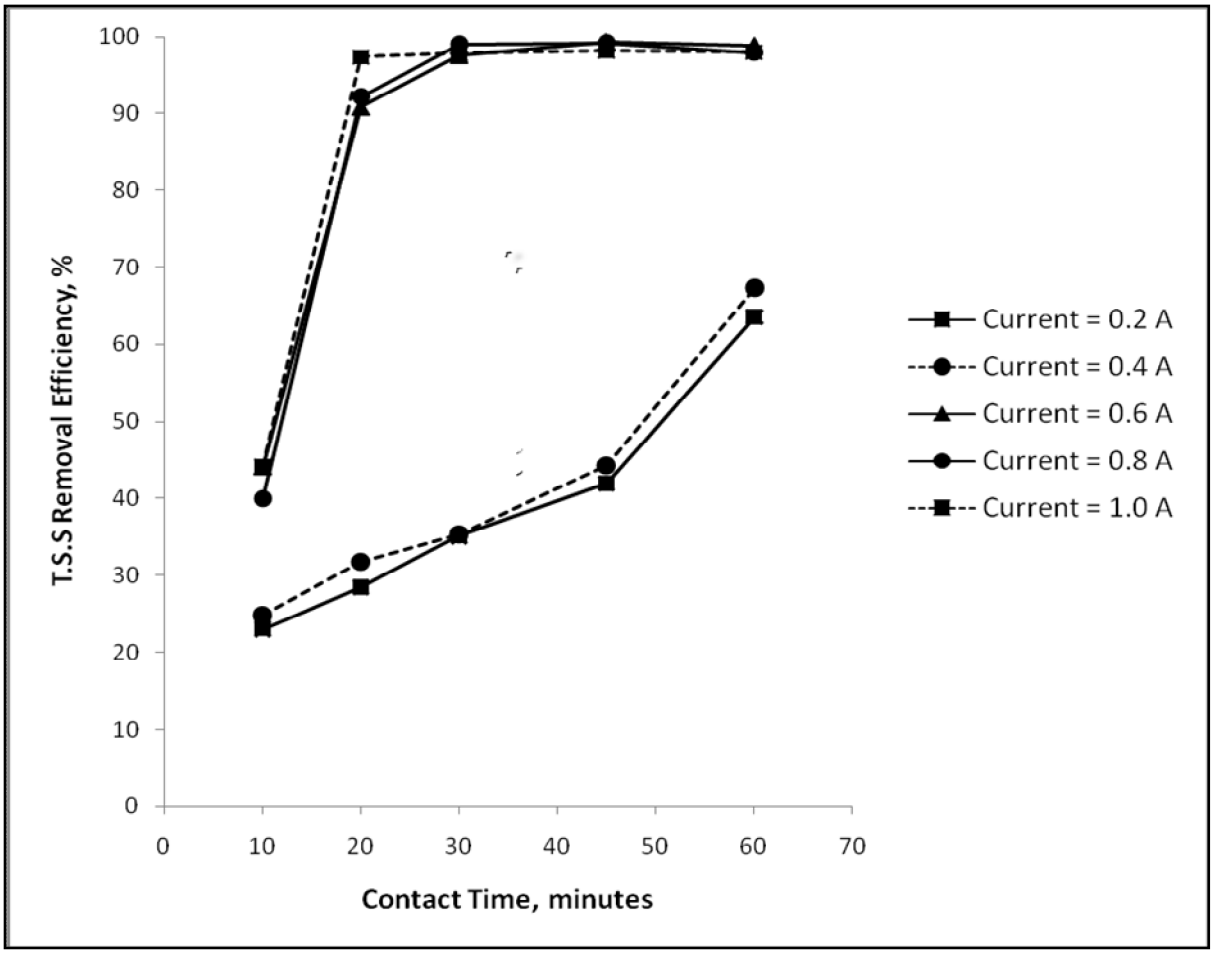

Figure 5-3: The relationship between TSS removal efficiency and contact time for the range of currents used in this study.

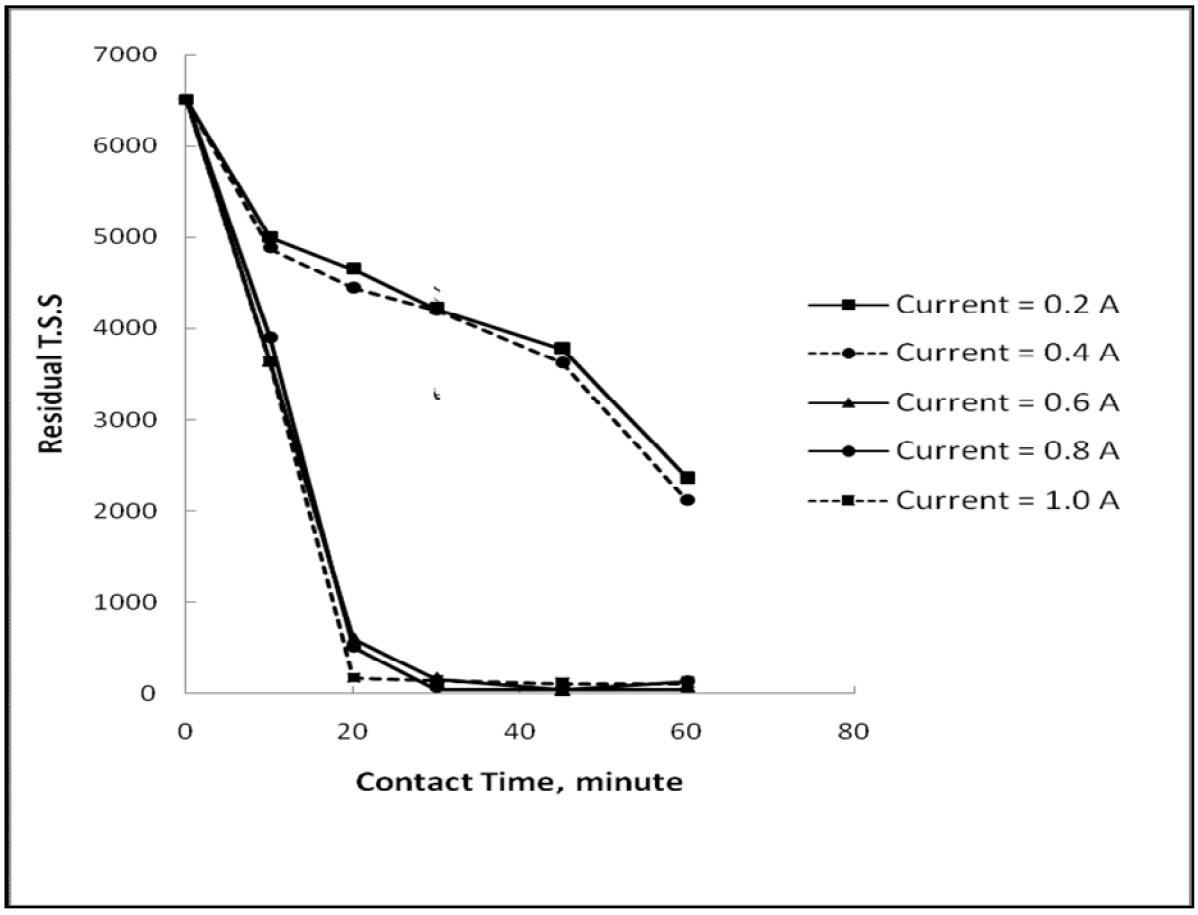

Figure 5-4: Residual TSS observed as a function of time for the currents used in this study

As mentioned in the literature review, the iron hydroxide produced from the anode as a result of the oxidation in the electrolytic system can either exist in the ferrous state, where iron carries two positive charges as in Eq. (5) or in the ferric state, where iron carries three positive charges as in Eq. (2). The ferric state which is commonly referred to as the oxidized state is much less soluble in water than the ferrous state. If Iron present in the soluble ferrous state, then we can postulate that the dominant mechanisms of particulate removal is charge neutralization (Bukhari, 2008). From this work, we can see that the trend of suspended solids removal at the lower currents of 0.2 A and 0.4 A are consistent with charge neutralization mechanism, where removal increases as the coagulant dose increases. The soluble ferrous form of iron can be converted to the insoluble ferric from by oxidation. The results obtained at the higher currents (0.4 A, 0.6 A and 0.8 A) suggest that the dominant mechanisms of particulate removal is sweep-floc coagulation. At such higher currents (higher potential) the ferrous iron is converted to insoluble ferric iron, hence, effecting sweep – floc coagulation. In support of our finding, it has been shown by Murugananthan et al., 2004 that the electro-coagualtion process using iron electrodes at higher potential favors the formation of Fe (III) ions. Precipitation of Fe (III) hydroxides has a better coagulating character than Fe (II) hydroxides (Zaroual et al., 2006). Additionally, Canizares had stated in his work that the addition of ferrous ions causes charge neutralization of colloids and hence agglomeration and settlement of flocs occur (Canizares et al., 2005).

The relationship between the turbidity removal efficiency and contact time for the different currents used is illustrated in Fig. 5-5. The figure shows that as the contact time increased from 10 to 60 min, removal efficiencies increased from 35% to 72% and from 38% to 74% for the currents of 0.2 A and 0.4 A as a function of time, respectively. Similar trend of sharp increase of turbidity removal efficiency in the first 20 min of contact time observed for the 0.6 A, 0.8 A and 1.0 A Current. However, further increase in contact time resulted in a slight increase in turbidity removal efficiency. The highest turbidity removal efficiencies of 72% and 74% for the 0.2 A and 0.4 A current occurred at contact time of 60 min for both currents. However, for higher currents of 0.6 A, 0.8 A and 1.0 A, the removal efficiency is observed to reach its maximum removal of 99%, 99% and 99% respectively. Also, it is observed that the removal efficiencies for all the higher currents oscillate between 92% to 99% after the first 10 min of contact time.

Fig. 5-6 shows the residual turbidity observed as a function of contact time for the range of currents used in this study. At a current of 0.2 A and 0.4 A, the residual turbidity is observed to decrease as the contact time increased. The lowest residual turbidity of 3650 NTU and 3330 NTU for 0.2 A and 0.4 A current, respectively, occurred at a contact time of 60 min. when the current increased to 0.6 A, 0.8 A and 1 A, the residual turbidity is observed to sharply decrease as a function of time at a higher rate than the 0.2 A and 0.4 A current. The lowest residual turbidity of 29.6 NTU, 48.6 NTU and 103 NTU for the 0.6 A, 0.8 A and 1.0 A current, respectively, occurred at a contact time of 45 min. These values were in compliance with standard prescribed in the GER (GER) of Presidency of Meteorology and Environment (PME).

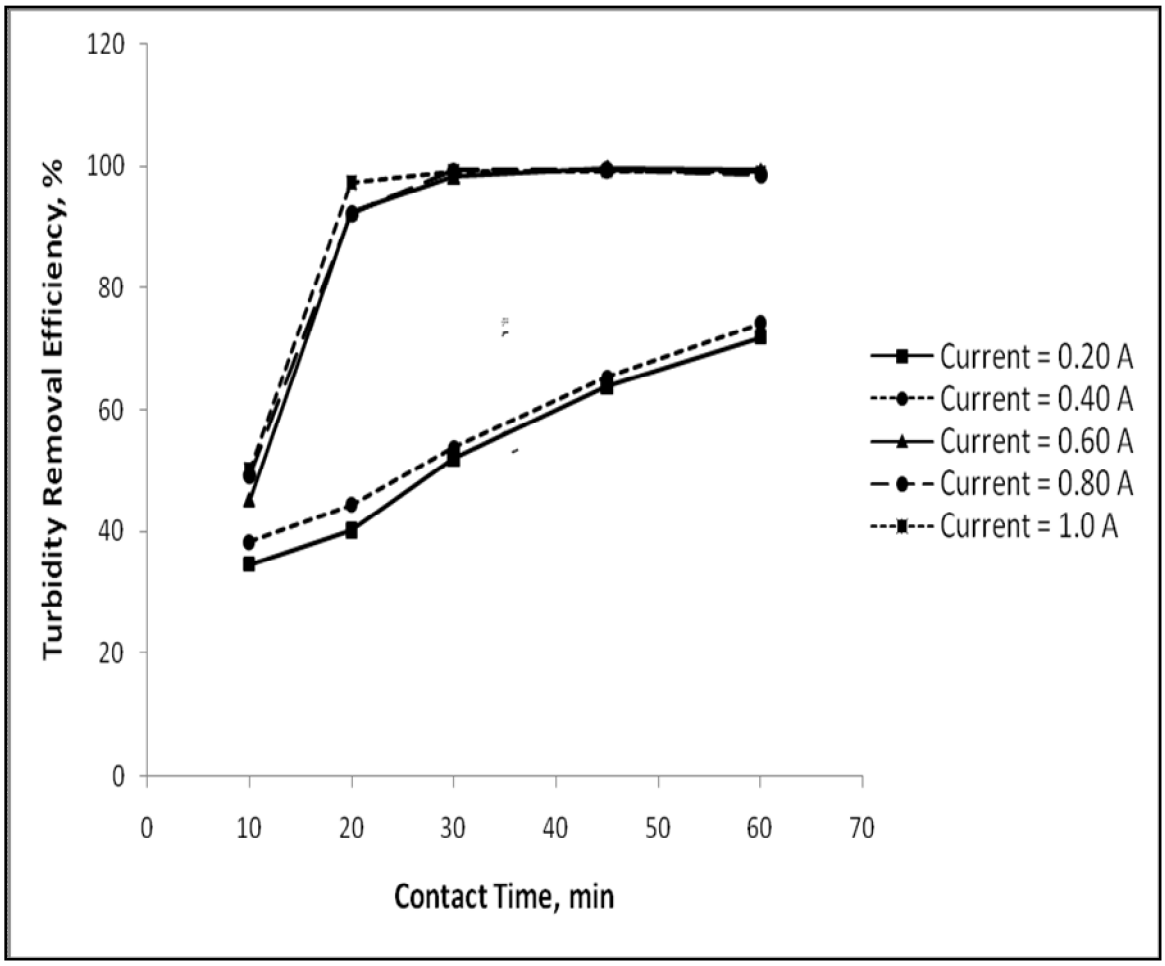

Figure 5-5: The relationship between turbidity removal efficiency and contact time for the range of currents used in this study.

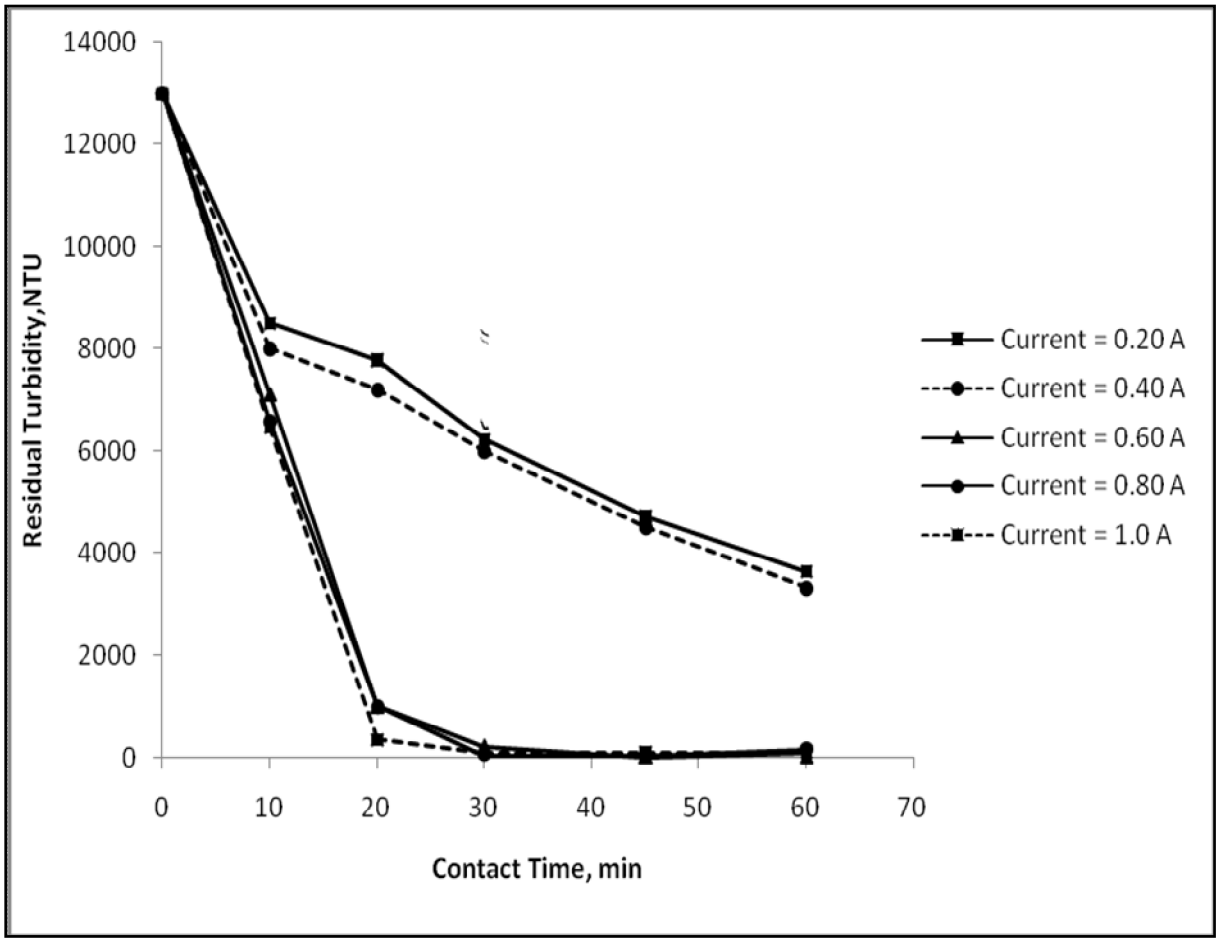

Figure 5-6: Residual turbidity observed as a function of contact time for the range of currents used.

Further investigations had been carried out to identify the organic constituents remaining after the treatment. It was found that there were no by-products compounds formed as a result of the chemical reaction occurred at the EC reactor. For this purpose, the sample that subjected to the current of 0.6 A and contact time of 20 minutes was used since it represents the optimum operating condition. The results showed that the compounds of C_7H_{16}, 1, 2-Ethanediol, Propyl glycol, C_8H_{18}, C_9H_{20}, $C_{10}H_{22}$, $C_{11}H_{24}$, C_{12} H_{26}, $C_{13}H_{28}$ disappeared after the treatment. The compounds left after the treatment were Propanoic acid -2-methyl-3-hydroxy-2,4-TMPE, 1-Mehoxy-2-propyl acetate, 1,3-Pentanediol-2,2,4-Trimethy, 2-Propanol, 1-methoxy (Table 5-4).

Table 5-4: Organic constituents identified at the optimum operating condition after the treatment

Sr.No	Retention Time	Compound Name
1	10.9	2-Propanol, 1-methoxy
2	16.4	1-Mehoxy-2-propyl acetate
3	23.2	1,3-Pentanediol-2,2,4-Trimethy
4	27.4	Propanoic acid -2-methyl-3-hydroxy-2,4-TMPE

The results of heavy metal ions concentration indicated that they were not of concern, because they were far below the pretreatment guidelines for discharge to central treatment facilities of PME. However, the heavy metals transition from the reactive electrode such as Cr^{+2} and Ni^{+2} during the treatment process were of concern on the water quality. Therefore, further analyses were performed. The pretreatment guidelines for the concerned heavy metals are provided in Table 5.5.

The detected heavy metals in the original wastewater were investigated at the optimum operating parameter where the analyses were carried out before and after the treatment. Figures 5-7 to 5-10 show the results for Ba, Cr, Ni and Zn, respectively. Figure 5-7 shows that the residual Ba had decreased sharply from 6.6 mg/l to 0.287 mg/l during the first 10 minutes. After that, the residual Ba continued gradually to decrease as a function of time. The lowest residual concentration of Ba achieved at 60 minutes where the value was 0.1 mg/l. From Figure 5-8, it can be seen that the residual Cr has increased as the contact time increased from 0 to 10 min and beyond that there was a gradual decrease of residual Cr up to 45 minutes. After which, there was neither decrease nor increase as a function of time. Figure 5-9 shows that the residual Ni had sharply increased from 0 to 10 minutes. Beyond the contact time of 10 minutes, residual Ni decreased as a function of time. The lowest residual concetration was observed at the contact time of 45 and 60 minutes. Figure 5-10 shows the residual Zn as a function of time. It can be seen that the residual Zn is oscillated from 0 to 60 min where the residual concentration at the contact time of 0 minutes was 0.44 mg/l, whereas the concentration at the contact time of 60 minutes was 0.416 mg/l.

Table 5-5: Pre-Treatment Guidelines of PME

Sr.No	Pollutants	Pre-Treatment Guidelines
1.	Barium (Ba)	Not Prescribed
2.	Chromium (Cr)	2 mg/l
3.	Nickel (Ni)	2 mg/l
4.	Lead (Pb)	1 mg/l
5.	Mercury (Hg)	0.01 mg/l
6.	Zinc (Zn)	10 mg/l

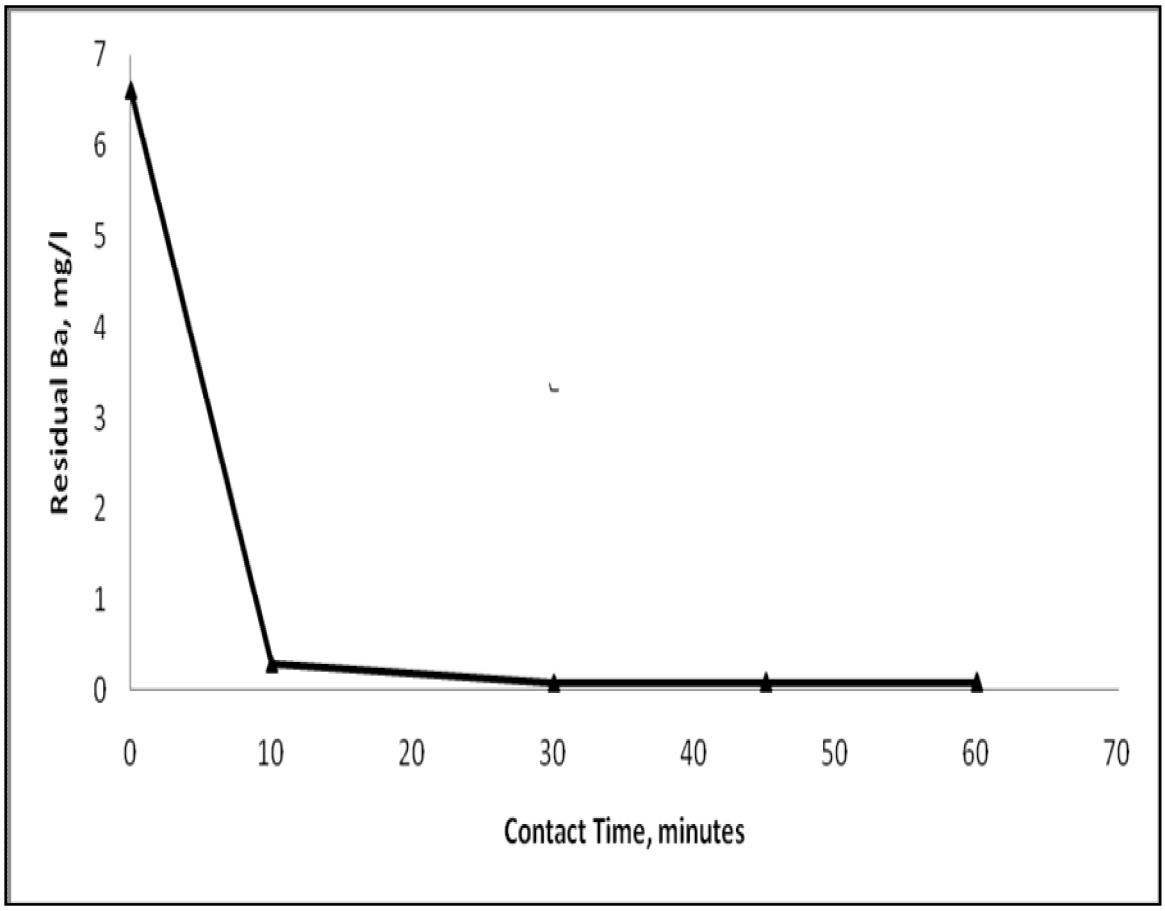

Figure 5-7: The relationship between residual Ba and the contact time.

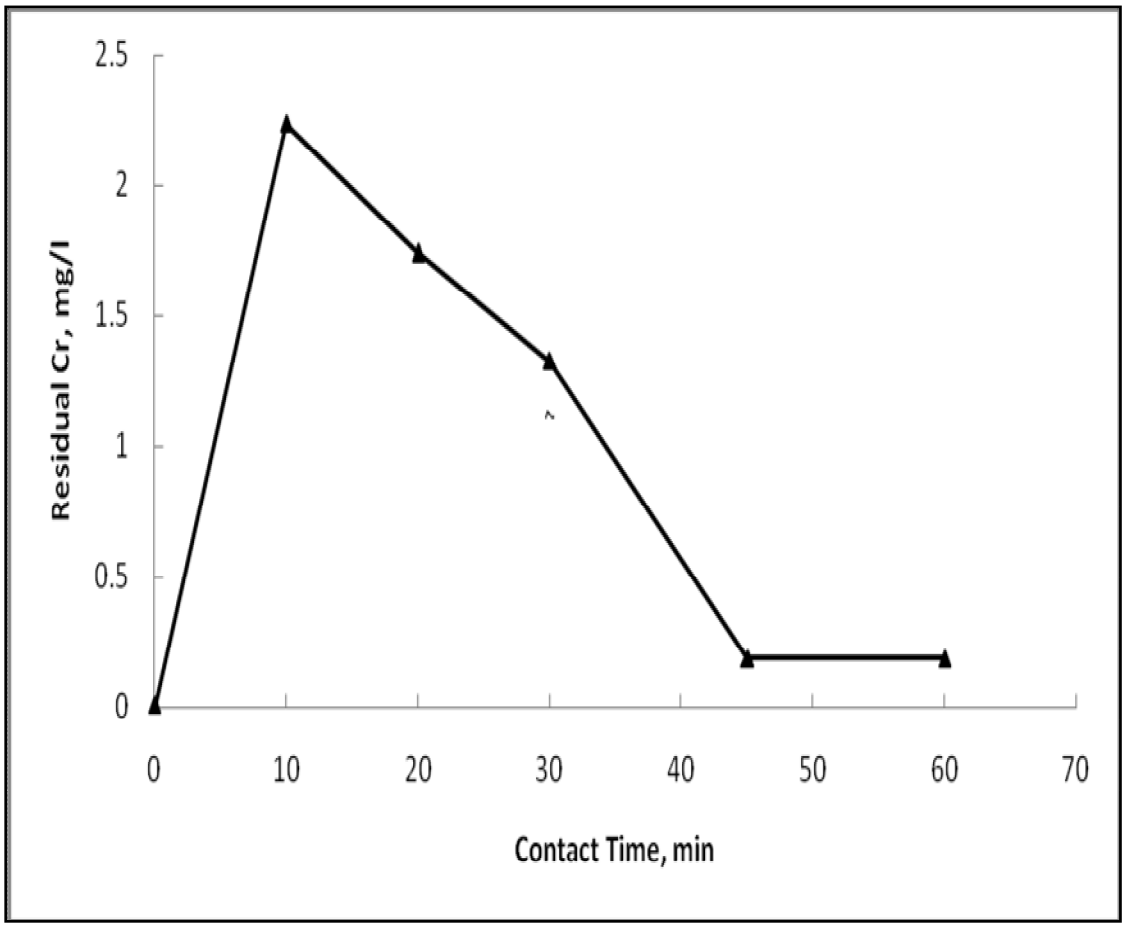

Figure 5-8: The relationship between residual Cr and contact time at current 0.6 A.

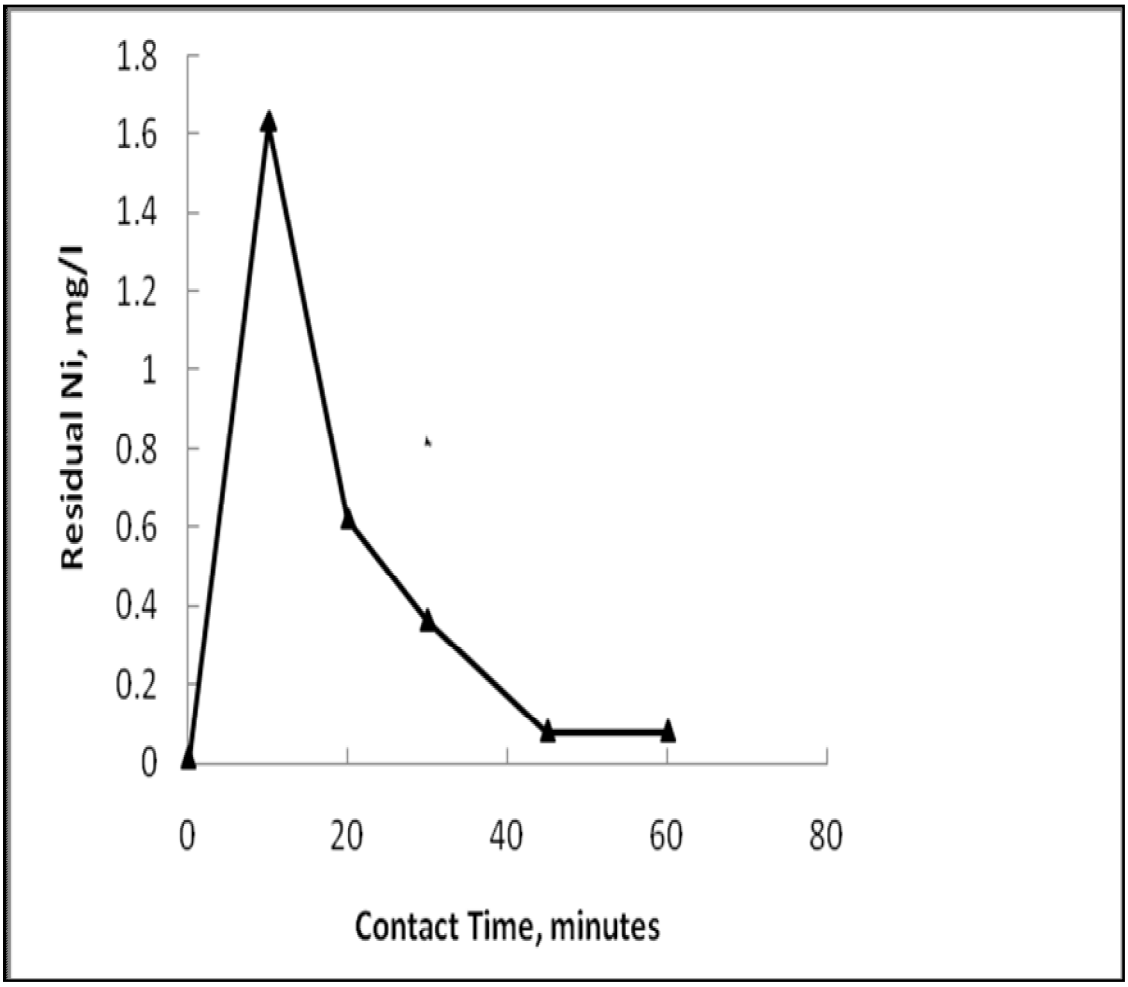

Figure 5-9: The relationship between residual Ni and contact time at current 0.6 A.

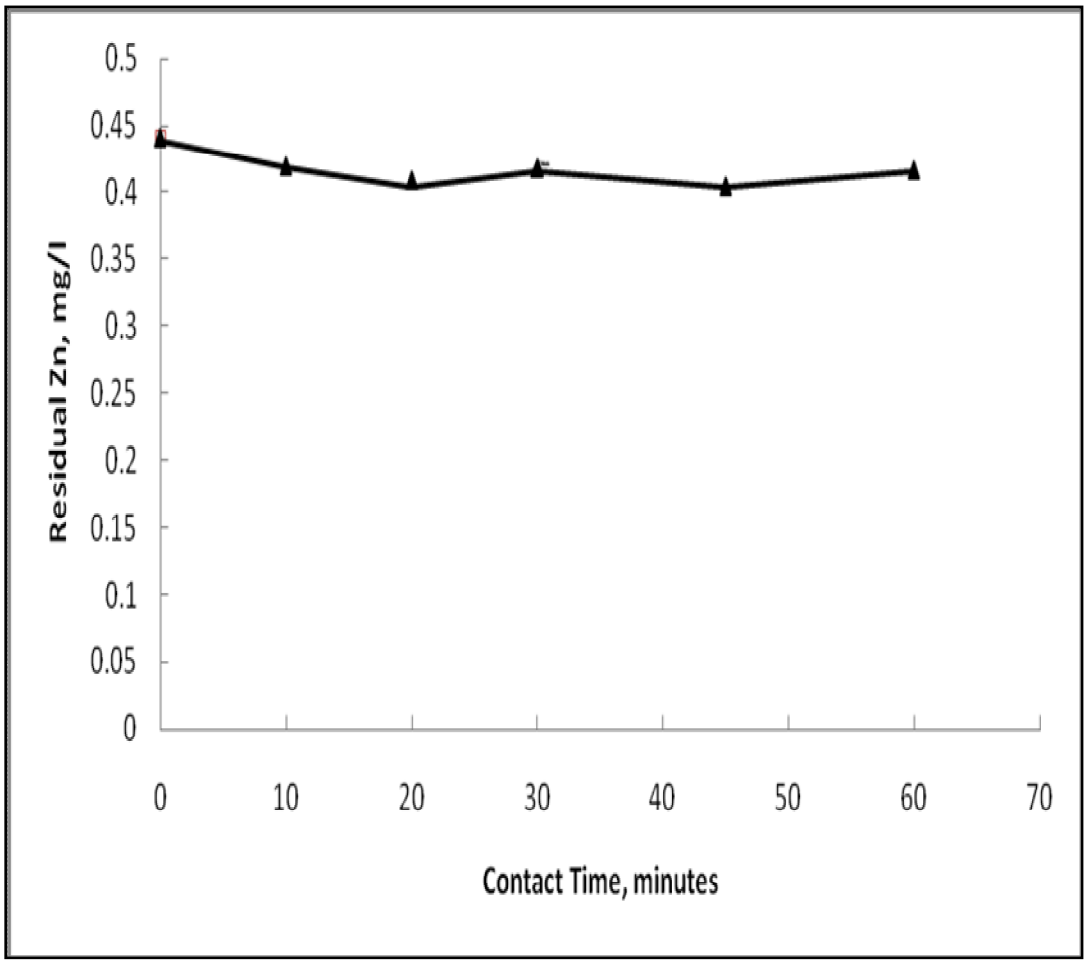

Figure 5-10: The relationship between residual Zn and contact time at current 0.6 A.

The increase of the concentration of Ni and Cr in the first 10 minutes during the treatment process could be attributed to the dissolution of the Ni and Cr contained in the stainless steel electrodes used in this study. According to Jumpatog & Buddhasukh (2003), Ni and Ba are hydrolyzed and co-precipitated as hydroxides which consist with the removal mechanism proposed. The removal mechanism for Cr could be attributed to the direct electrochemical metal reduction (here Cr (VI) to Cr (III)) occurs at the cathode:

$Cr_2O_7^{-2} + 6e^- + 7H_2O \rightarrow 2\ Cr^{3+} + 14OH^-$

Subsequently, the hydroxide ions formed at the cathode increase the pH of the wastewater and may induce precipitation of Cr (III) in the form of its corresponding hydroxide:

$Cr_{(aq)}^{+3} + 3OH^- \rightarrow Cr\ (OH)_{3\ (s)}$

The stability of Zn concentration could be attributed to the interferences caused by some compounds which prevent the precipitation. Also, the low initial metal concentration could be a possible reason for preventing the Zn to precipitate as hydroxides.

5.3 COD, TSS and Turbidity Removal Efficiencies in Terms of Iron (Fe) Generated

The current density had a large effect on the kinetics of the waste treatment for COD, TSS and turbidity removal efficiencies. Higher current densities required shorter contact times to reach the maximum removal. The effect of current density is linked to the production of in-situ generated iron, produced during electrolysis (Abuzaid et al., 2002; Larue et al., 2002). Therefore, it was important to calculate the amount of iron electrically dissolved and hence to observe the COD, TSS and Turbidity removal efficiencies in terms of iron production. This was done by using Faraday's law; relating the mass (C_{Fe}) of electrolytically generated iron going into the solution to the operating current (I) and the contact time (t).

$$C_{Fe} = \frac{I \times t \times M}{z \times F} \tag{15}$$

where, M is the atomic weight of iron, z is the number of electrons transferred in the anodic dissolution (here $z = 2$) and F is the Faraday's constant (96500 C/mol).

Using equation (15), the amount of coagulant produced was calculated. Thus Figures 5-11 to 5-13 show the system's response not on a simple time basis but as a function of the total amount of coagulant put into the solution.

Figure 5-11 shows the relationship between the COD removal efficiency with respect to the amount of iron generated. It can be seen that the COD removal efficiency for the current of 0.2 A, 0.4 A and 0.6 A is dependant of the amount of iron released into the solution. As the amount of iron released increases, COD removal efficiency increases proportionally up to 104 mg/l, 278 mg/l and 417 mg/l, respectively. Beyond that, the excess coagulant doses resulted in a slight decrease in COD removal efficiency. However, as the current increased to 0.8 A, the COD removal efficiency is also dependant on the amount of iron released up to 625 mg/l. after that, the amount of iron generated resulted in slight decrease in COD removal efficiency. For the 1.0 A current the COD removal efficiency increased from 18% to 70 % as the contact time increased from 10 min to 20 min and beyond the 20 min no further increase in COD removal efficiency is observed. Considering the fact that soluble COD could not be removed in this process for the wastewater studied, we can say that 104 mg/l, 278 mg/l, 417 mg/l, 625 mg/l, 417 mg/l of iron dosages required for the removal of suspended COD for the currents of 0.2 A, 0.4 A, 0.6 A, 0.8 A and 1.0 A, respectively. Further addition of the coagulant will only produce more sludge without affecting the removal efficiency of the treatment process.

Fig. 5-12 shows TSS removal efficiency as a function of the amount of iron generated for the different currents used in this study. It can be seen that the removal efficiency for lower currents of 0.2 A and 0.4 A is dependent of the amount of iron generated. In other words, as the amount of iron generated increases, removal efficiency increases proportionally. However, as the current increased to 0.6 A and higher, the relationship

between removal efficiency and amount of iron released is no longer valid. Fig. 5-13 shows the turbidity removal efficiency as a function of the amount of iron released for the different currents used in this study. It can be observed that turbidity removal efficiency for the currents of 0.2 A, 0.4 A and 0.6 A is dependent of the amount of iron released. As the amount of iron released increases, the turbidity removal efficiency increases proportionally. However, as the current increased to 0.8 A and 1.0 A the turbidity removal efficiencies increase as the coagulant doses increase at a certain value of 313 mg/l and 417 mg/l, respectively. Beyond that the excess of the coagulant doses is no longer valid. The increase of amount of iron release resulted in the stabilization of the turbidity removal efficiency.

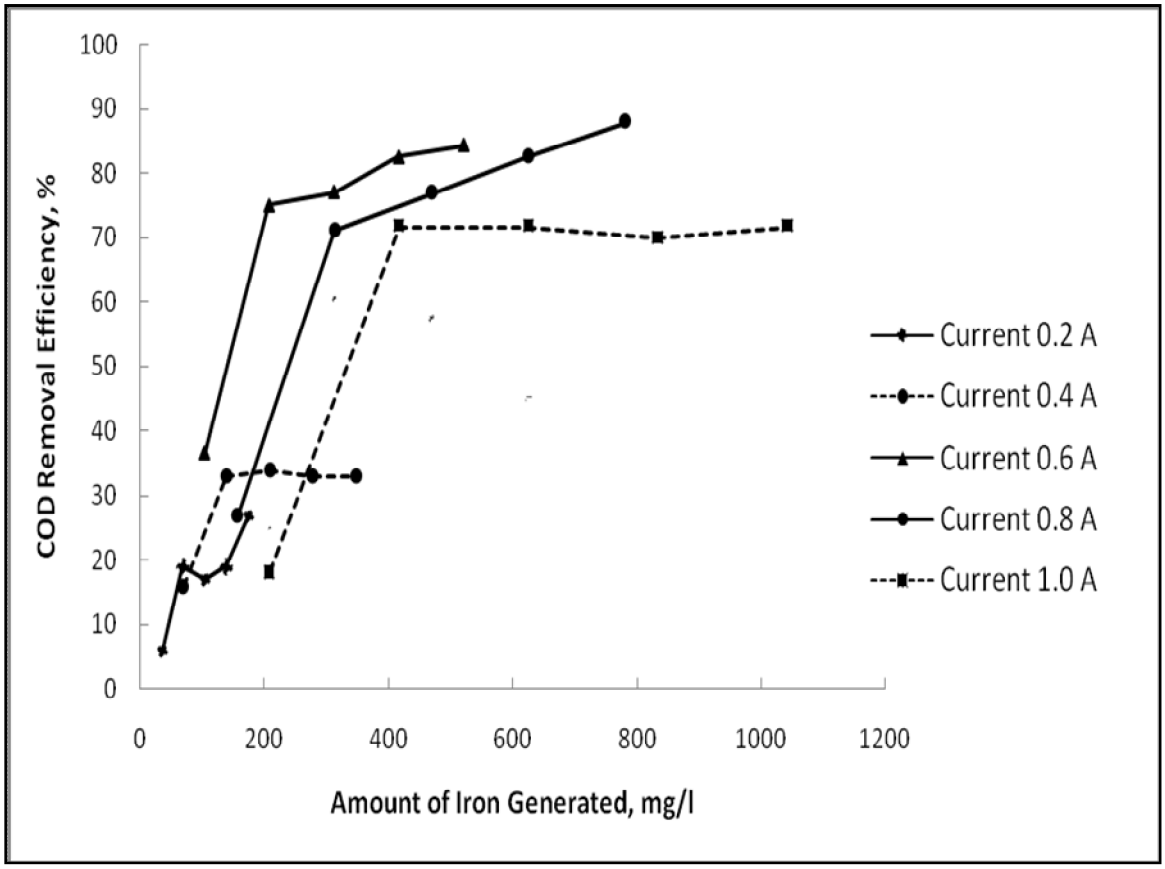

Figure 5-11: COD removal efficiency as a function of the amount of iron generated.

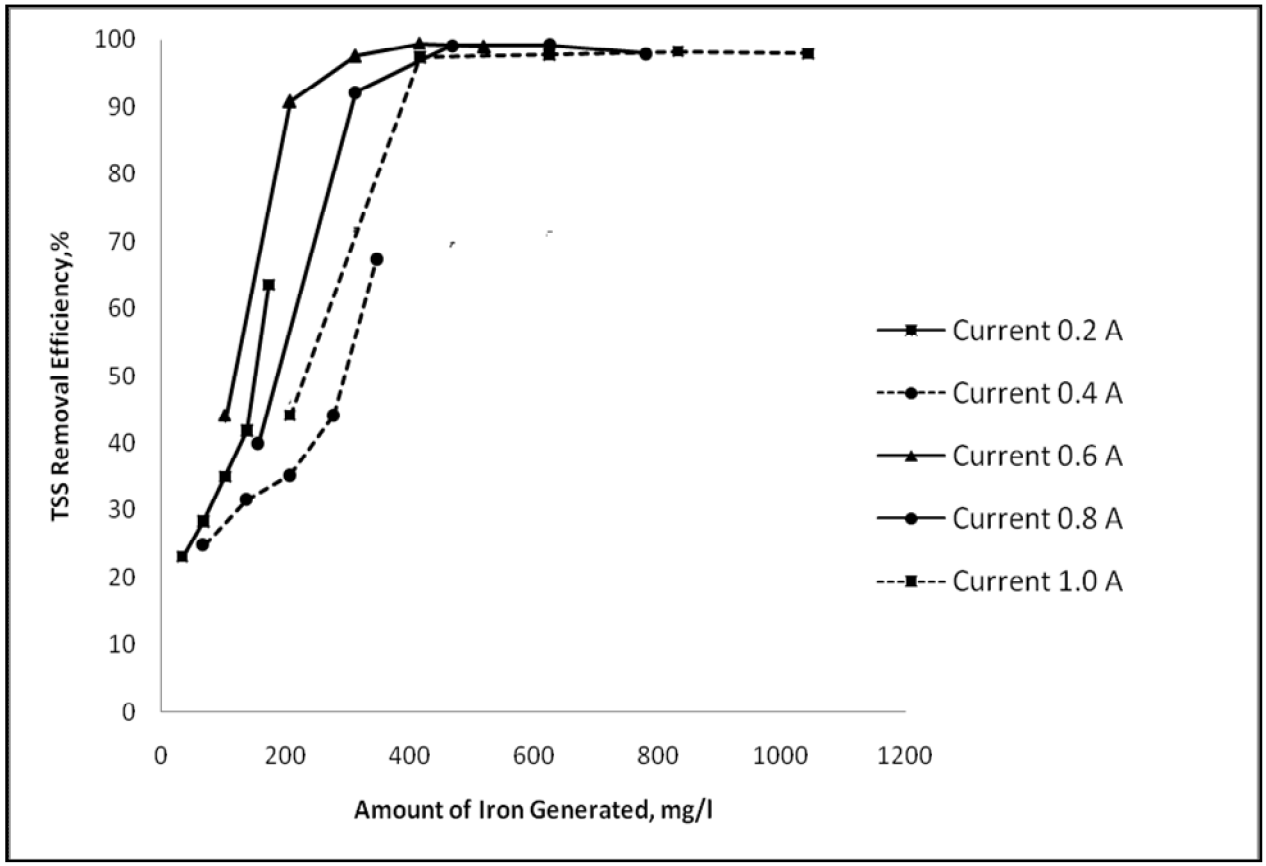

Figure 5-12: TSS removal efficiency as a function of the amount of iron generated.

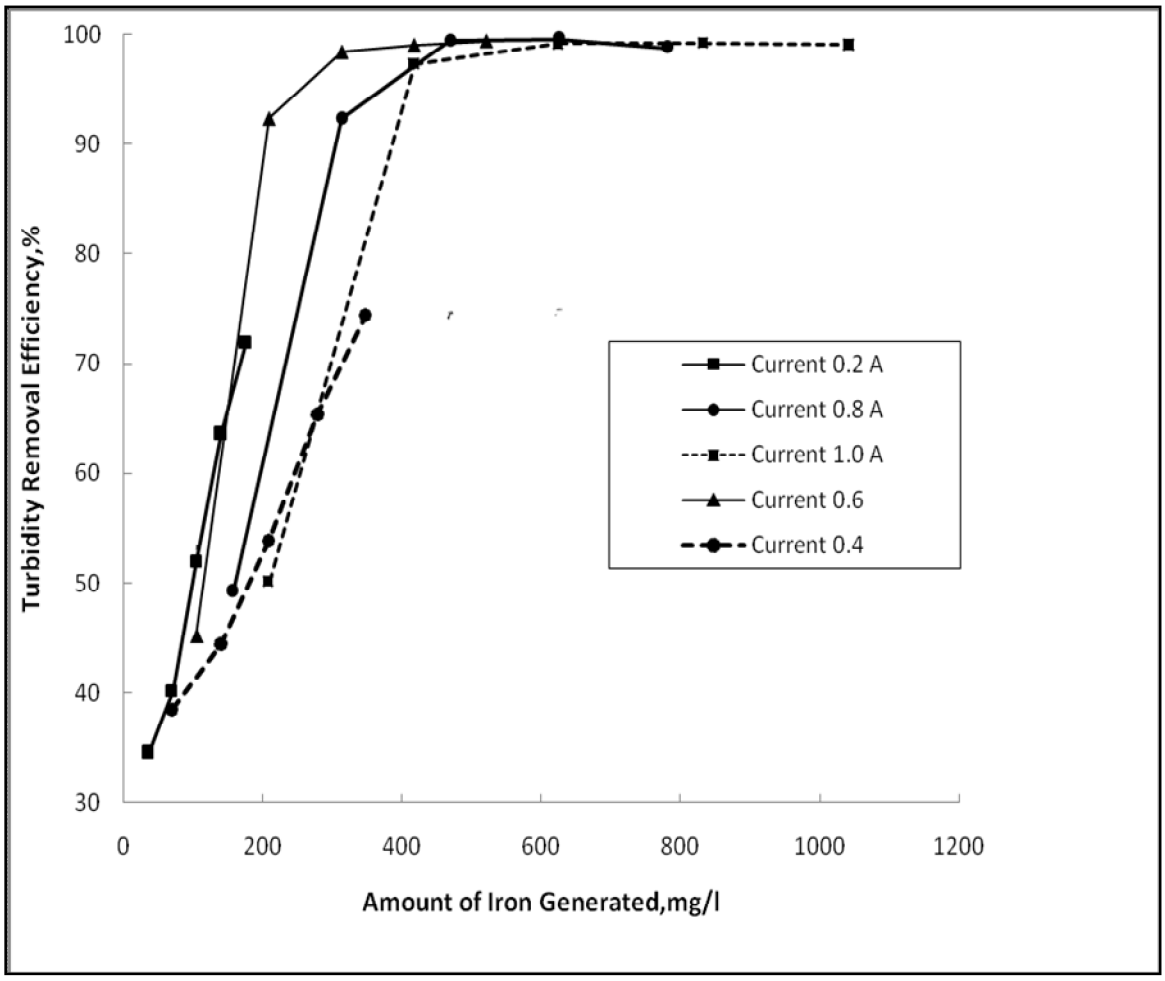

Figure 5-13: Turbidity removal efficiency as a function of the amount of iron generated.

5.4 INVESTIGATING THE EXTENT OF ELECTROOXIDATION

In an Electrochemical cell, the governing processes for the removal of any contaminant are electro-oxidation and/or electro-coagulation. It is known that Electrooxidation (EO) takes part in removal the soluble organic compounds (referred to as Dissolved Chemical Oxygen Demand) due to the formation of chlorine gas. Therefore, this research aimed to investigate the extent of Electrooxidation (EO) within the process in the treatment of paint industry wastewater.

From the results obtained (Section 5.1), it was noticed that the maximum removal efficiency for COD was 88%. This removal efficiency was represented by the two mechanisms. Hence, to separate the effect of EO and EC, Physical (filtration) tests were performed to observe the DCOD removal efficiency trends. The COD of the suspended solid was determined by measuring the total COD of the sample before filtering through 0.25 µm filter paper (Particulate plus soluble COD) and after filtration (soluble COD). The difference between the two measurements gives the particulate COD.

Figure 5.14 shows that extent of the electrooxidation mechanism compared to electocoagualtion. It can be seen that as the contact time increased from 10 to 30 min, the DCOD slightly increased from 3.7% to 4.0 %, and beyond which, the removal starts to oscillate between 4.0% and 4.1% efficiencies. Figure 5.15 shows the DCOD residual as a function of time.

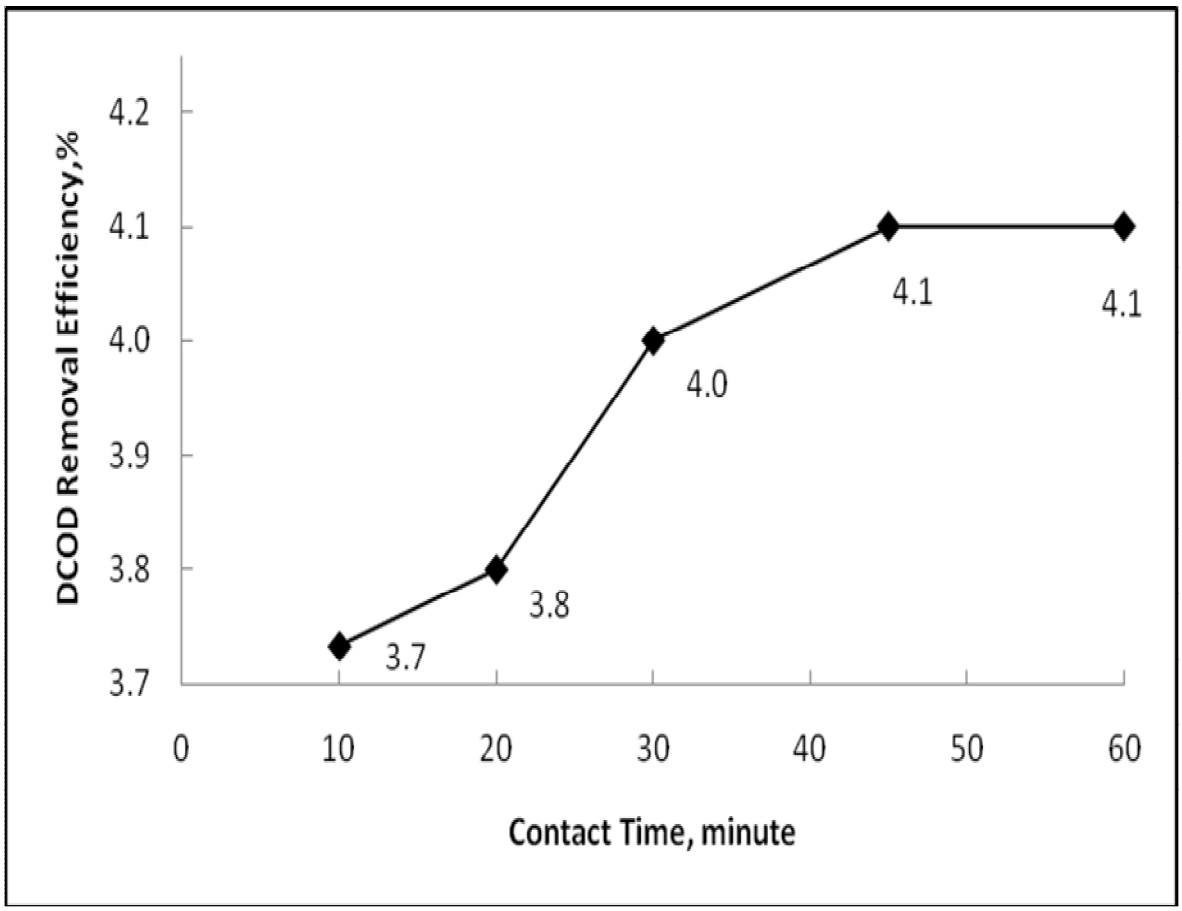

Figure 5.14: The relationship between DCOD Removal Efficiency and Contact Time at 0.6 A with 2000 mg/l of NaCl.

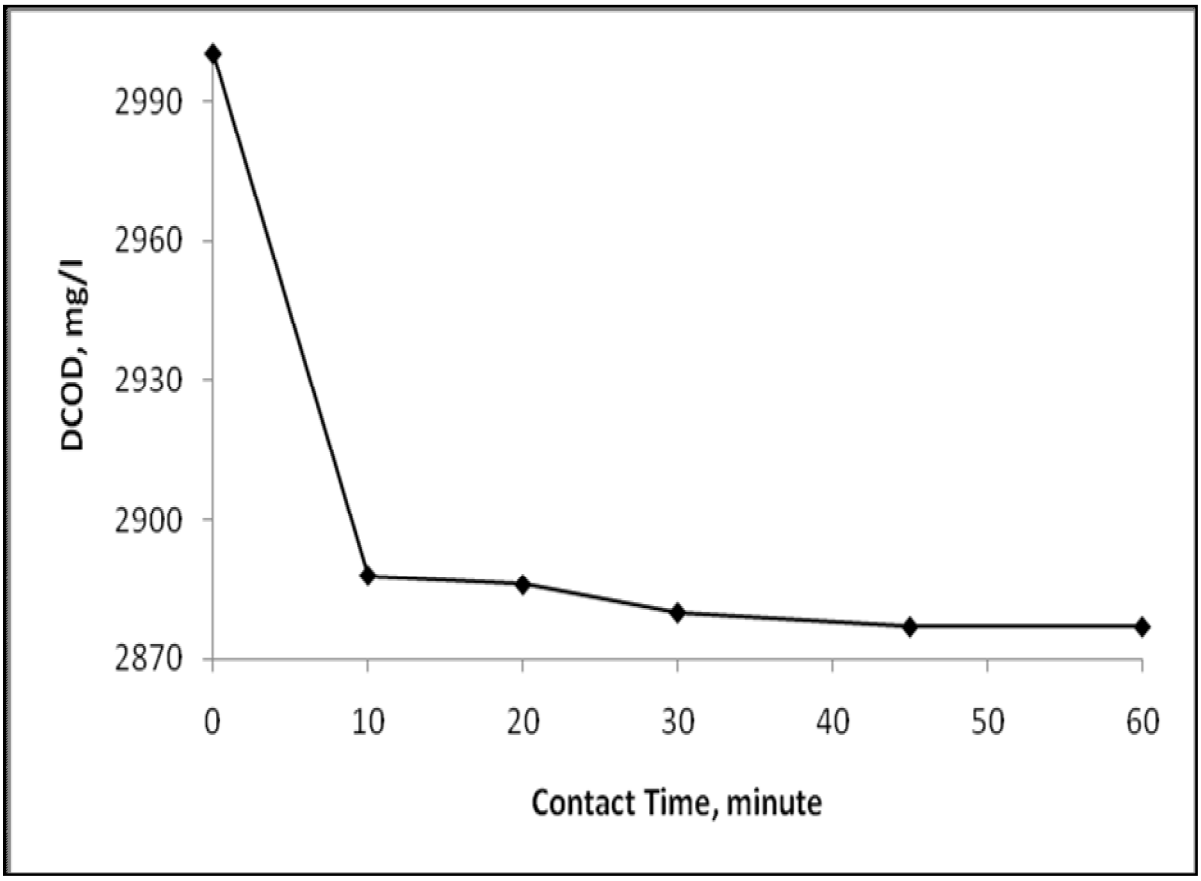

Figure 5.15: The relationship between residual DCOD and Contact Time at 0.6 A with 2000 mg/l of NaCl.

5.5 PH Variation

According to literature (Vik et al., 1984), pH has a considerable effect on the efficiency of the electrocoagulation process. In addition, pH changes during the process dependent on the anode material and the initial pH value of the treated solution.In this research, initial pH of the samples was 7.4. Final pH depends on the current and contact time supplied. It was observed that with the increase of current and contact time, pH of the treated samples increased. This occurs due to the evolution of hydrogen gas produced at the surface of the cathode. Higher currents and contact times result in higher generation of hydrogen gas, which produces more alkaline treated samples.

Figure 5-15 shows the pH variation with time and the current. The pH value did not exceed 8.73. It was observed from the results obtained from treating this type of this wastewater that the range of pH from 7.4 to 8.73 did not inversely affect the removal efficiencies for COD, T.S.S and Turbidity. It can be seen from the figure that as the time and current increase, a gradual increase in pH value takes place.

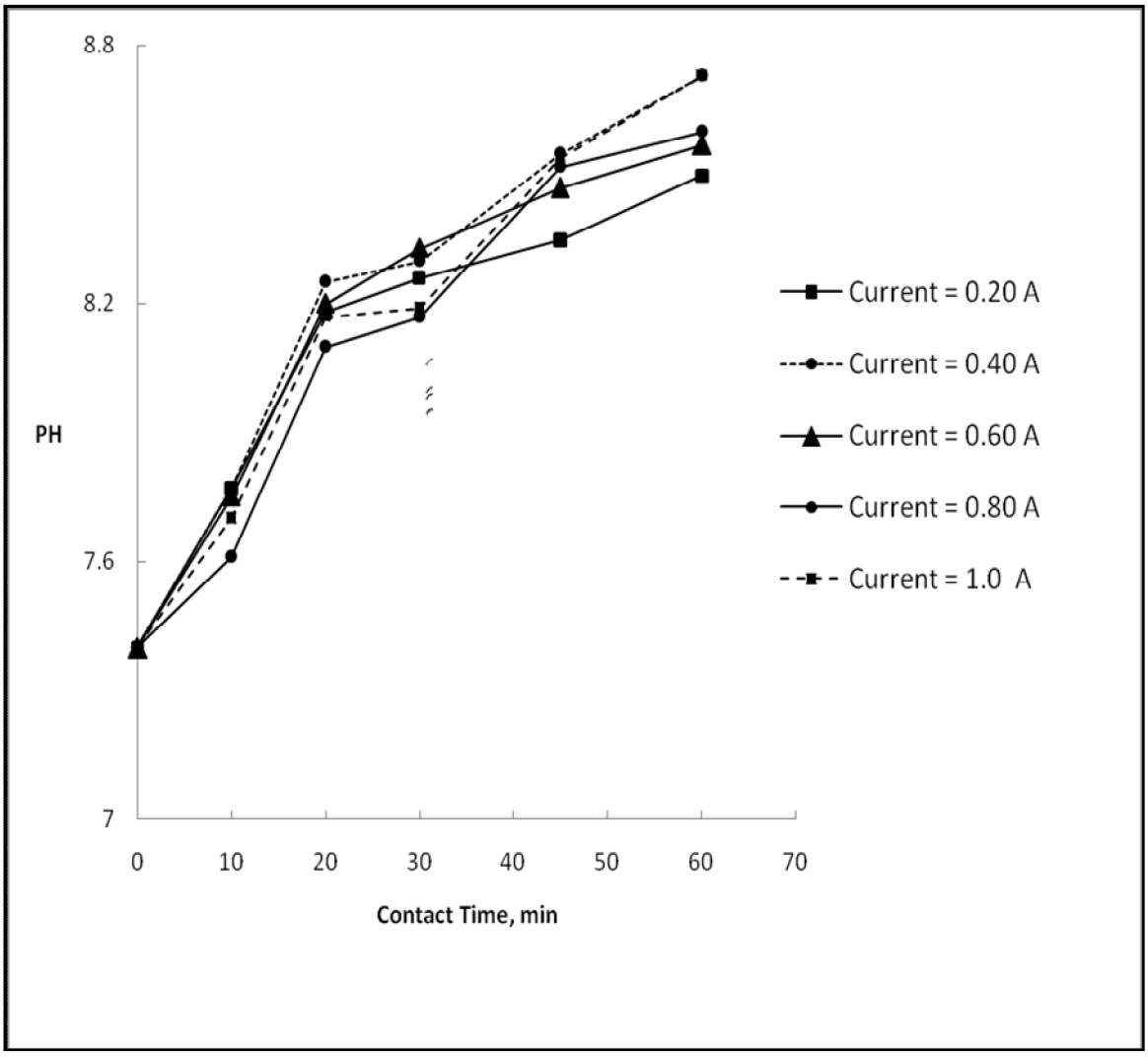

Figure 5-15: pH trend during the treatment.

5.6 EFFECT OF ELECTROLYTE CONCENTRATION AND DETERMINATION OF ENERGY CONSUMPTION

Sodium chloride (NaCl) may be used to increase the conductivity of the wastewater to be treated with electrochemical process. Solution conductivity affects the current efficiency, cell voltage and consumption of electrical energy in electrolytic cells. Higher ionic strength causes an increase in current density at the same voltage, or, equivalently, the cell voltage decreases with increasing wastewater conductivity at constant current density. Consequently, the necessary voltage for attaining a certain current density will be diminished and the consumed electrical energy will decrease. However, a very high conductivity may lead to secondary reactions, which will reduce the removal efficiency.

To investigate the effect of the conductivity on the process in terms of COD, turbidity and TSS and to determine the energy consumption, Sodium Chloride (NaCl) was added to the electrolytic cell in different concentration. The concentrations added to the cell were 2000, 3000 and 4000 mg/l. The investigations were carried out at the optimum operating parameter (0.6 A). The results showed that the increase of conductivity by adding the NaCl had influenced the removal efficiencies of COD, TSS and turbidity only during the first 10 min of the treatment process where the removal efficiency of COD had increased from 37% (before the addition) to 59%, 58% and 56% after the addition NaCl of 2000, 3000 and 4000 mg/l, respectively. After which, the increase of conductivity did not influence the removal efficiencies of COD, TSS and turbidity compared with the results obtained before the addition (Fig 5-16, Fig. 5.17 and Fig. 5.18). Additionally, it was seen that the cell potential decreased significantly with the addition of salt, due to the decrease in the ohmic losses. Therefore, we can say that in the range of electrolyte

concentration studied, no significant change in the removal efficiencies were obtained but the consumption of electrical energy had been decreased due to its addition.

The current efficiency, cell voltages and consumption of electrical energy in electrolytic cells may get affected by the conductivity of the solution. Increasing solution conductivity using NaCl has other advantages, i.e. chloride ions could significantly reduce the adverse effects of other anions, such as HCO_3^- and SO_4^{2-} (Chen, 2006). However, a very high conductivity may lead to secondary reactions, consequently diminishing the main reaction of electrolytic decomposition of iron electrodes.

According to Ohm's law, the Power (P) is the amount of current times the voltage level at a given point measured in wattage or watts. The Energy consumption is the power times time. Figure 5.19 shows the relationship between the energy consumption with respect to different concentration of NaCl. It can be seen from the figure the energy consumption decreased dramatically after the addition of NaCl of 2000, 3000 and 4000 mg/l. The addition of the 3000 and 4000 mg/l of NaCl did significantly decrease the energy consumption compared with the addition of 2000 mg/l of NaCl.

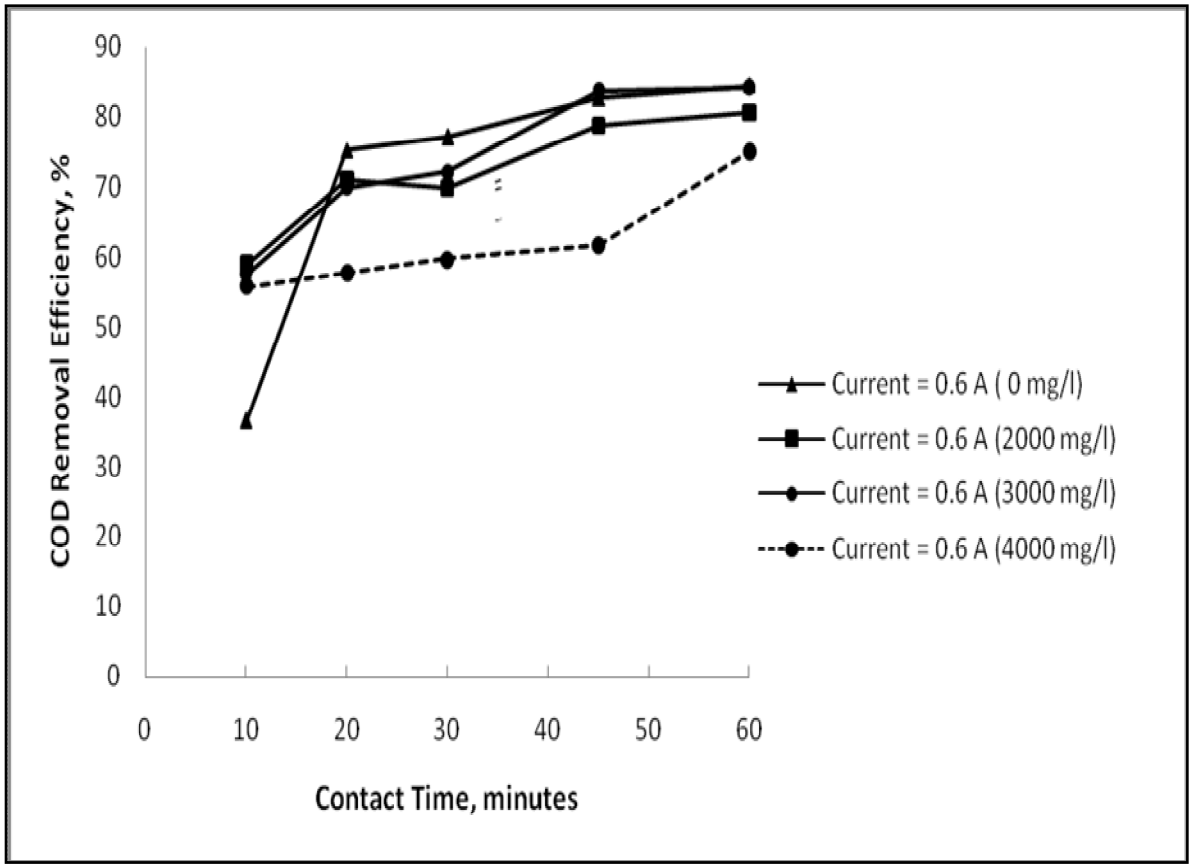

Figure 5-16: Effect of current on COD removal efficiency with respect to time after adding NaCl.

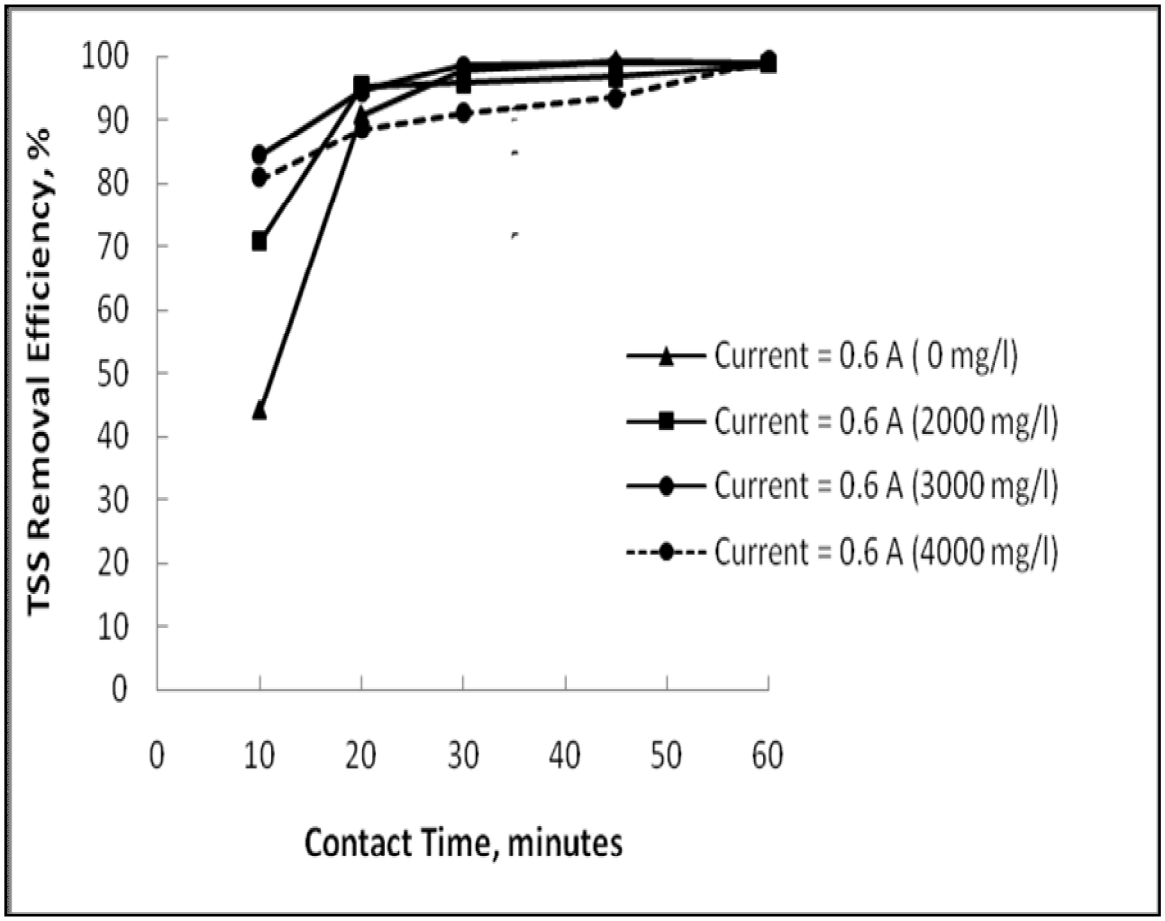

Figure 5-17: Effect of current on TSS removal efficiency with respect to time after adding NaCl.

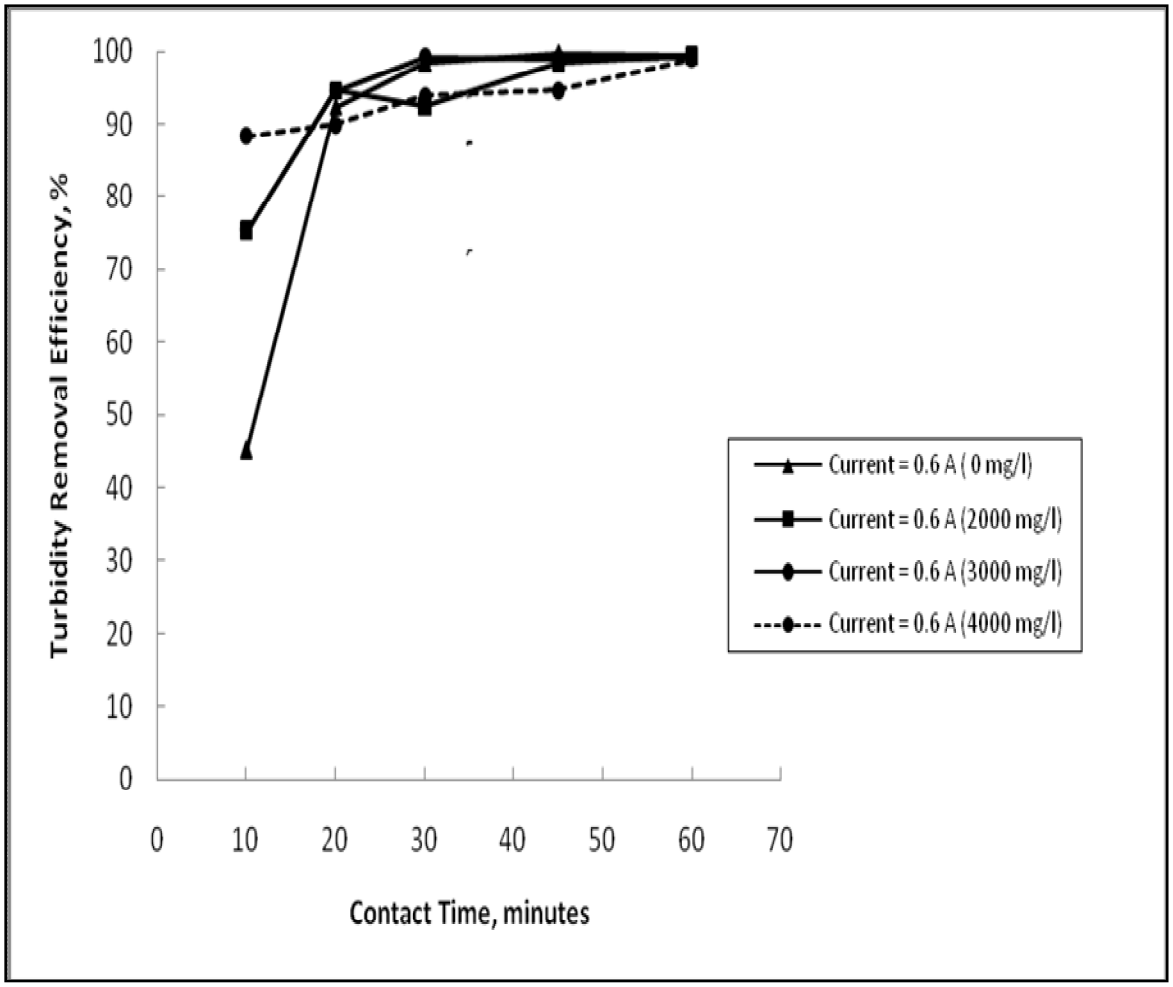

Figure 5-18: Effect of current on turbidity removal efficiency with respect to time after adding NaCl..

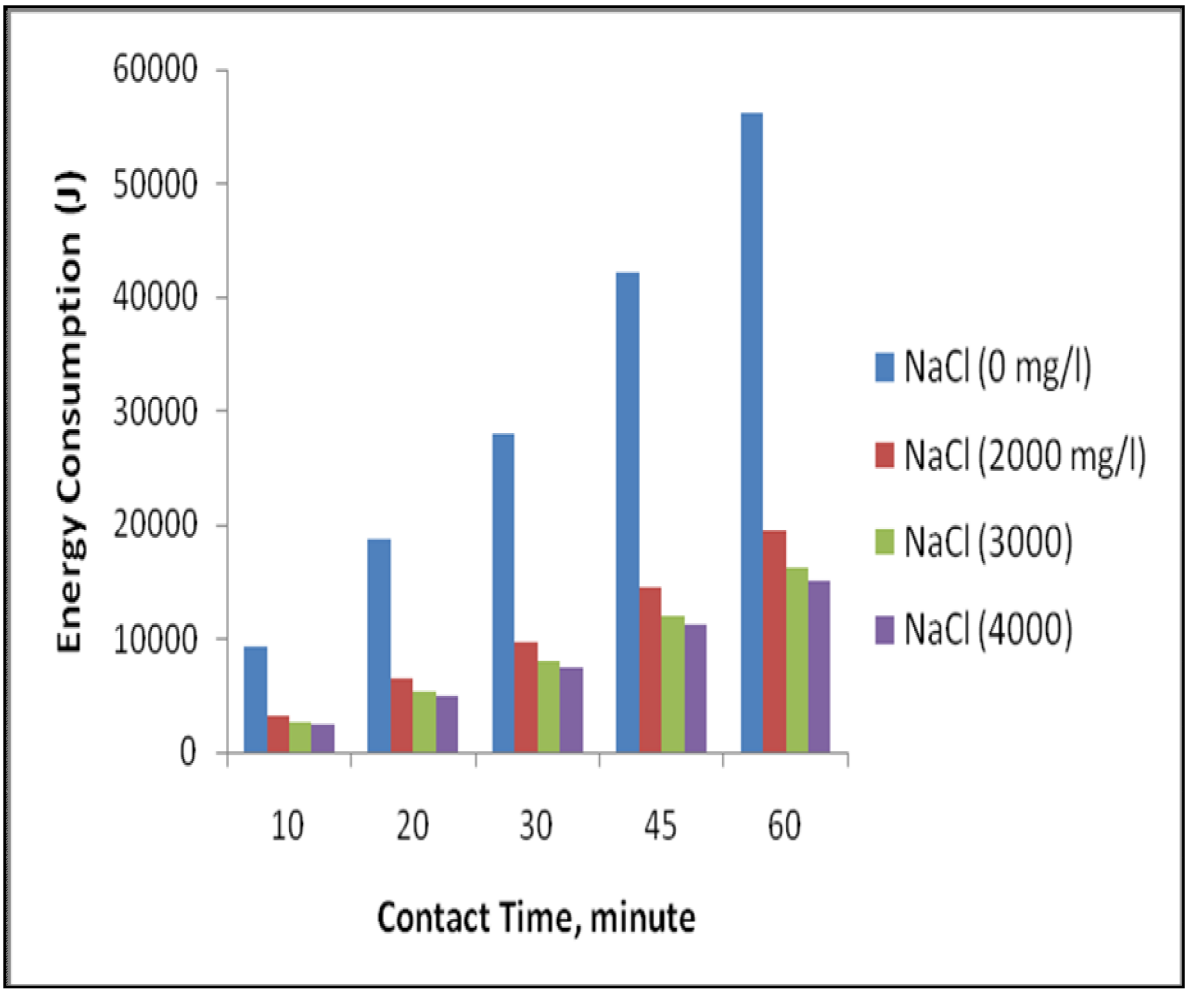

Figure 5-19: The Energy Consumption with respect to Different Concentration of NaCl.

CHAPTER 6

CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS

After conducting this research, the following conclusions can be drawn:

1) The current density had a significant effect on the COD, turbidity, TSS removal efficiencies.
2) Higher current densities required shorter contact times to reach the maximum removal efficiency.
3) It was observed that the removal of TSS and turbidity was mainly associated with the amount of iron released when applying low currents (0.2 and 0.4 A). On the other hand, for higher currents (0.6, 0.8 and 1.0 A) this relationship was no longer valid after the contact time of 20 min.
4) Initially, the flocs were destabilized due to the presence of Fe(II) ions and flocculation occurred due to charge neutralization. At later stages, sweep coagualtion also occurred due to the dominance of iron hydroxide species.
5) It was proved that the main dominant mechanism to remove the suspended COD was Electrocoagulation.
6) Increase in salinity had no significant effect on the overall removal efficiency.

RECOMMENDATIONS

1) Further research is required to investigate the effect of electrocoagulation on the heavy metals.
2) Economic analysis should be done to analyze the feasibility of electrocoagulation as a pretreatment process for the wastewater studied.
3) If the initial conductivity of this type of wastewater is around 1300 μS/cm, then the addition of electrolyte to investigate the enhancement in removal is not recommended.
4) Further research is recommended to assess the subject of sludge production.

APPENDIX
(Experimental Raw Data)

Table A-1.Data sheet for value of pH with 0 g/l electrolyte concentration

Current(A)	Contact Time (min)	pH
0.2	0	7.4
	1	7.77
	20	8.18
	30	8.26
	45	8.35
	60	8.73
0.4	0	7.4
	10	7.77
	20	8.25
	30	8.3
	45	8.55
	60	8.73
0.6	0	7.4
	10	7.75
	20	7.95
	30	8.33
	45	8.41
	60	8.57
0.8	0	7.4
	10	7.61
	20	7.83
	30	8.17
	45	8.52
	60	8.6
1.0	0	7.4
	10	7.7
	20	8.17
	30	8.19
	45	8.54
	60	8.7

Table A-2.Analysis of results for residual and removal efficiency of COD with 0 g/l electrolyte concentration

Current (A)	Contact Time (min)	Residual COD (mg/l)	Removal Efficiency
0.2	0	19136	-----
	10	18032	6
	20	15456	19
	30	15900	17
	45	15456	19
	60	13984	27
0.4	0	19136	-----
	10	16008	16
	20	12880	33
	30	12696	34
	45	12880	33
	60	12880	33
0.6	0	19136	-----
	10	12144	37
	20	4784	75
	30	4400	77
	45	3350	82
	60	3000	84
0.8	0	19136	-----
	10	13984	27
	20	5520	71
	30	4416	77
	45	3312	83
	60	2208	88
1.0	0	19136	-----
	10	15660	18
	20	5400	72
	30	5400	72
	45	5760	70
	60	5400	72

Table A-3.Data sheet for residual and the removal efficiency of TSS with 0 g/l electrolyte concentration.

Current (A)	Contact Time (min)	Residual TSS (mg/l)	TSS Removal Efficiency
0.2	0	6500	-----
	10	5000	23
	20	4650	28
	30	4220	35
	45	3777	42
	60	2367	64
0.4	0	6500	-----
	10	4880	25
	20	4440	32
	30	4200	35
	45	3620	44
	60	2120	67
0.6	0	6500	-----
	10	3633	44
	20	600	91
	30	160	98
	45	40	99
	60	72	99
0.8	0	6500	-----
	10	3900	40
	20	508	92
	30	60	99
	45	48	99
	60	132	98
1.0	0	6500	-----
	10	3628	44
	20	167	97
	30	140	98
	45	110	98
	60	130	98

Table A-4.Analysis of results for residual and the removal efficiency of Turbidity with 0 g/l electrolyte concentration.

Current (A)	Contact Time (min)	Residual Turbidity	Turbidity Removal
0.2	0	13000	-----
	10	8500	35
	20	7777	40
	30	6240	52
	45	4720	64
	60	3650	72
0.4	0	13000	-----
	10	8000	38
	20	7220	44
	30	6000	54
	45	4500	65
	60	3330	74
0.6	0	13000	-----
	10	7120	45
	20	1000	92
	30	213	98
	45	30	100
	60	82	99
0.8	0	13000	-----
	10	6600	49
	20	1000	92
	30	77	99
	45	49	100
	60	162	99
1.0	0	13000	-----
	10	6475	50
	20	354	97
	30	117	99
	45	103	99
	60	125	99

Table A-5.Analysis of results for the value of the parameters after adding NaCl at current 0.6 A

Current (A)	Electrolyte Conc. (mg/l)	Contact time (min)	Final COD (ppm)	Final Turbidity (NTU)	Final pH	Final TSS (mg/l)
0.6	0	10	37	45.2	7.4	44
		20	75	92.3	7.75	91
		30	77	98.4	7.95	98
		45	82	99.8	8.33	99
		60	84	99.4	8.41	99
0.6	1000	10	14	75.4	7.4	71
		20	57	94.5	7.74	95
		30	63	92.4	7.84	96
		45	79	98.3	7.9	97
		60	81	99.4	8.01	99
0.6	2000	10	10	75.4	7.4	84
		20	62	94.5	7.46	94
		30	72	99.2	7.51	99
		45	84	99.7	7.63	97
		60	84	99.4	7.83	99
0.6	3000	10	56	88.5	7.4	81
		20	58	89.8	7.53	88
		30	60	93.8	7.48	91
		45	62	94.7	7.75	93
		60	75	99.6	7.87	99

REFERENCES

Abo Alhassan, M., Souabi, S., Yaacoubi, A., Baudu, M., 2006. *Improvement of paint effluents coagulation using natural and synthetic coagulant aids.* Journal of Hazardous Materials. France.

Abuzaid, N., Bukhari, A., Al-Hamouz, Z., 1998. *Removal of bentonite causing turbidity by electrocoagualtion.* Journal of Environmental Science and Health A 33 (7), 1341-1358.

Adhoum, N., Monser, L., 2004. *Decolourization and removal of phenolic compounds from olive millwastewater by electrocoagulation*, Chem. Eng. Proc. (43) 1281–1287.

Bahadir, K., Nahit, K., Tanyolaç, A., 2006. *Optimization of electrochemical treatment of industrial paint wastewater with response surface methodology* .Journal of Hazardous Materials (114). 199–205.

Brown, J., Weintraub, M., 1982. *Biooxidation of paint process wastewater*, Water Pollut. Control Fed. (54), 1127–1130.

Bukhari, A. (2007). *Investigation of the electrocoagualtion treatment process for the removal of total suspended solids and turbidity from municipal wastewater*. Bioresource technology (99). 914-921.

Bukhari, A., Abuzaid, N., Abdulappa, M., Essa, M. 1999. *Pretreatment of domestic wastewater in an electrochemical cell. In: the fifth Saudi engineering conference*, vol.3, p. 293.

Canizares, P., Martinez, F., Carmona, M., Lobato, ., Rodrigo, M., 2005. *Continuous electrocoagulation of synthetic colloid-polluted wastes*, Ind. Eng.Chem. Res. 8171–8177.

Carmona, M.,. Khemis, M., Lecler, J., Lapicque, F., 2006. *A simple model to predict the removal of oil suspensions from water using the electrocoagulation technique*, Chem. Eng. Sci. (61), 1237–1246.

Chen, G., *Electrochemical Technologies in Wastewater Treatment*, Separation and Purification Technology, 38(1): 11-41, 2004.

Comninellis, C. 1994. *Electrocatalysis in the Electrochemical Conversion/Combustion of Organic Pollutants for Wastewater Treatment, Electrochim*. Acta, 39: 1857–1862.

Díaz, C., Pardavé, M., Romo, M., Martínez, S . 2003. *Chemical and electrochemical considerations on the removal process of hexavalent chromium from aqueous media*, J. Appl. Electrochem. 33. 61–71.

Dovletoglou, O. Philippopoulos, C. Grigoropoulou, H. 2002. *Coagulation for treatment of paint industry wastewater*, J. Environ. Sci.1361–1377.

El-Gohary, F.A. Wahaab, R.A. Nasr, F.A. Ali, H.I. 2002. *Three Egyptian industrialwastewater management programmes*, 59–65.

Gondal M., Hussain. T., 2004. *Determination of poisonous metals in wastewater collected from paint manufacturing plant using laser-induced breakdown spectroscopy*. Journal of Hazardous Materials (114), 199–210.

Holt, P., Barton, G., Mitchell, C. 2005. *The Future for Electrocoagulation as a Localised Water Treatment Technology,* Chemosphere.

Holt, P., Barton, G., Mitchell, C, 1999. *Electrocoagulation as a Wastewater Treatment*, Third Annual Environmental Engineering Research Event, 23-26,.

Idris, A., Saed, K., 2003. *Possible Utilization of Silica gel for removal of phenol from aqueous*. Journal of the Environmentalist, (23),4, 329-334.

Jehangir, M., 2006. *Treatment of Simulated Dairy Wastewater by Electrocoagulation,* King Fahd University of Petroleum & Minerals.

Jiang, J., Graham, N., André, C., Kelsall, G., Brandon, N. 2002. *Laboratory study of electro-coagulation-flotation for water treatment*, Water Res. 36 .4064–4078.

Joffe, L., Knieper, L., 2000. *Electro-coagulation technology quickly removes barium total suspended solids from a water-retention pond for fractions of a cent per gallon*.

Jumpatog, K., Buddhasukh, D. 2003. *Electrocoagulagtion of some metals*. Industrial Wastewater Journal.

Kobya, M. Senturk, E. Bayramoglu, M. 2006. *Treatment of poultry slaughterhouse wastewaters by electrocoagulation,* J. Hazard. Mater. 133. 172–176.

Kobya, M., Bayramoglu, M., Eyvaz, M., 2007. *Techno-economical evaluation of electrocoagulation for the textile wastewater using different electrode connections*. Journal of Hazardous Materials (148), 311–318.

Kumar, P.., Chaudhari, S., Khilar, K.., Majan, S. 2004. *Removal of arsenic from water by electrocoagulation,* Chemosphere 55.1245–1252.

Kurt, U., Apaydin, O., Gonullu, M. 2006. *Reduction of COD in wastewater from an organized tannery industrial region by Electro-Fenton process*. Journal of Hazardous Material. (143). 33- 40.

Kurt, U., Gonullu, M.T. Avsar, Y. Arslankaya, E. 2002. *Research on treatability of Young landfill leachates by Fenton's reaction*, World Environmental Congress and Exhibition, Istanbul.

Kutluay, G. Babuna, F.G. Eremektar, G. Orhon, D. 2004. *Treatability of water-based paint industry effluents*, Fresenius Environ. 1057–1060.

Larue, O., Vorobiev, E., Vu, C., Durand, B. 2003. *Electrocoagulation and Coagulation by Iron of Latex Particles in Aqueous Suspensions*, Separation and Purification Technology, 31: 177-192.

Lin, H., Ho, S. 1996. Catalytic wet-air oxidation of high strength industrial wastewater. Department of Chemical Engineering, Yuan Ze Institute of Technology. 133- 147.

Mahesh, S., Prasad, B., Mall,I., Mishra, I. 2006. *Electrochemical degradation of pulp and paper mill wastewater. Part 1. COD and color removal*, Ind. Eng. Chem. Res. (45), 2830–2839.

Matteson, M.J., Dobson, R.L., Glenn, R.W., Kukunoor, N.S. Waits III, W.H., Clayfield, E.J. 1995. *Electrocoagulation and Separation of Aqueous Suspensions of Ultrafine Particles*, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 104: 101-109.

Mollaha, M., Morkovskyb, P., Gomesc, J., Kesmezc, M., Pargad, J., Cocke, D. 2004. *Fundamentals present and future perspectives of electrocoagulation Journal of Hazardous Materials*. 114 (1-3), 199-210.

Murugananthan, M. Bhaskar, R.G. Prabhakar, S. 2004. *Separation of pollutants from tannery effluents by electroflotation*, Purif. Technol. 69–75.

Pulgarin, C., Adler, N., Péringer, P., Comninellis, C., 1994. *Electrochemical detoxification of a 1,4-benzoquinone solution in wastewater treatment,Water*. Res. (28) 887–893.

Rajeshwar, K., Ibanez, J., 1997. *Environmental electrochemistry: fundamentals and applications in pollution abatement.* Chemical Degradation Methods for Wastes and Pollutants. Academic USA Press.

Sayinera, G., Kandemirli, F., Dimoglo, A., 2008. *Evaluation of boron removal by Water Pollut*. Control Fed. S1127–1130.

Scott, K., 1995. *Electrochemical Processes for Clean Technology*, UK. The Royal Society of Chemistry.

Strydom, J.P., Mostert, J.F., Britz, T.J.,1995. *Anaerobic Treatment of a Synthetic Dairy Effluent using a Hybrid Digester*, Water Science, 21(2): 125-30.

Sun, B., Sato, M., Clements, J. 2000. *Oxidative Processes Occurring when Pulsed High Voltage Discharges Degrade Phenol in Aqueous Solution*, Environmental Science and Technology, 34: 509–513.

Szpyrkowicz, L., Kelsall, G.H., Kaul, S.N., Faveri, M.D., *Performance of Electrochemical Reactor for Treatment of Tannery Wastewaters*, Chemical Engineering Science, 56: 1579–1586, 2001.

Zaroual, Z., Azzi, M., Saib, N., Chainet, E. 2006. *Contribution to the study of electrocoagualtion mechanism in basic textile effluent.* Journal of Hazardous Materials B 131 (1-3), 73-78.

Zor, S., Yazici, B., Erbil, A., 2006. Removal of linearalkylbenzenesulphonate (LAS) from aqueous solutions by electrocoagulation, Bull. Electrochem. (22), 241–248.

VITA

Professional History
- Environmental Consulting Bureau (ECB) 2007-Present
- Royal Scientific Society – Environmental Research Center (ERC) 2005-2007

Degrees
- M.S. (Environmental Engineering)- King Fahd University of Petroleum & Minerals, KSA
- B.E.(Water and Wastewater Engineering) Al- Balq'a Applied University,

Affiliations & Continuing Education
- Jordan Engineers Association
- Saudi Councel of Engineers

Language Skills
- English
- Arabic

Technical Specialties
- Wastewater Treatment Plant
- Social and Environmental Impact Assessment studies
- Regulatory Compliance Audit
- Internal Audit against ISO 14001 and OHSAS 18001 standards
- Environmental Applicability Reviews
- Environmental Information Reports
- Risk Assessment for Occupational Health and Safety (OHSAS 18001) and Environmental Management System (ISO 14001) standards
- Emission Inventories
- Air Dispersion Modeling

Mr. Sawalha is ECB's Business Development Manager, who is responsible to explore projects opportunities in Middle East market, build relationships, develop the proper Scope of Work (SOW) for the governmental and industrial projects, and execute projects. Mr. Sawalha has a diversified experience in the field of Environment. He has been involved with key clients such as the SABIC, Saudi Aramco, Presidency of Meteorology and Environment (PME), Bahrain Petrochemical Company (BAPCO), Royal Commission, Ministry of Water and Electricity (MOWE), etc.

With the time he has spent at ECB, he has participated in the development of proposals for key clients, conducted several Environmental health and safety awareness trainings, executed compliance audits, generated Environmental Information reports, Conducted several Environmental Impact Assessment studies for sensitive projects, and managed several Air Dispersion modeling studies.

Al-Jazeerah National Electric Cable Factory, *Category-III (Class A) Environmental Impact Assessment (EIA) study for a proposed cable factory in the Light Industrial Park (LIP)- Yanbu Industrial City:* **(Senior Consultant)**

Ministry of Water and Electricity (MOWE), *Category-III (Class A) Environmental Impact Assessment (EIA) studies for proposed and existing Sewage Treatement Plants (STPs) at Al Kharj, Al Haier and Manfouha in line with the PME, Equator Principles, and World Bank- IFC EHS standards and guideline:* **(Senior Consultant)**

Abalkhail Consulting Engineers, *Category-III (Class A) Environmental Impact Assessment (EIA) study for the existing Jeddah-Khumrah STP and a proposed outfall in line with the PME standards* **(Senior Consultant)**

Saudi Arabian Bechtel Company, *Category-III (Class A) Environmental Impanct Assessment Study for the construction, commissioning and operational phases of the "Installation of Riyadh Refinery Crude Oil Pipeline" in line with the Saudi Aramco SAEP-13 procedure and PME standards* **(Project Manager)**

Malakoff and Sumitomo Consortium, *Environmental Scoping and Social Impact Assessment Study (SEA) for the proposed Ras Az Zawr Independent Water and Power Plant (IWPP) in line with the requirements PME and Equator Principles of 2006* **(Senior Consultant)**

Saudi Arabian Bechtel Company, *Category-II (Class B) Environmental Impact Assessment Study for the "Installation of 1.3 KM loop line between NRBP to NRTU corridors" in line with the Saudi Aramco SAEP-13 procedure and PME standards* **(Project Manager)**

Petrocon Arabia Limited (PAL), *Category-II (Class B) Environmental Impact Assessment Study for "Relocating Northern Area Pipelines RTJ-1 and NQRT-1" in line with the Saudi Aramco SAEP-13 procedure and PME* **(Senior Consultant)**

.

Saudi Consolidated Engineering Company (SCEC), *Category-II (Class B) Environmental Impact Assessment Study for the "Construction of new aviation building at Khafji Joint Operations (KJO) 1.5Km southwest of KJO refinery" in line with the Saudi Aramco SAEP-13 procedure and PME*. **(Project Manager)**

Petrocon Arabia Limited (PAL), *Category-II (Class B) Environmental Impact Assessment Study for "Installation of 18.5Km new Propane pipeline from Ra Tanura Refinery to Juaymah Gas Plant in line with the Saudi Aramco SAEP-13 procedure and PME*. **(Consultant)**

Saudi Consulting and Design Office (SCADO), *Category-II (Class B) Environmental Impact Assessment Study for the "Construction of new North park Office Complex at the North Park area- Dhahran in line with the Saudi Aramco SAEP-13 procedure and PME standards.* **(Consultant)**

Fawaz Al Hokair Group, *Category-III (Class A) Environmental Impanct Assessment Study for the construction, commissioning and operational phases of the "Commercial and Residential Development project" in line with the PME standards* **(Consultant)**

Ghawar Facilities Capacity Optimization, An Environmental impact Assessment report was performed for Saudi Aramco for crude pipeline with length 140 Km in Ghawer Field (KSA) (Consultant).

Developing the KSA Standards, The project included reviewing and upgrading the Kingdom of Saudi Arabia Environmental Standards and training courses for 32 Environmental inspectors about the General Environmental Regulation and Role for implementation (GERARFI) for 7 months. (Consultant).

Manifa Downstream pipeline project, An Environmental Impact Assessment Report was conducted for Saudi Aramco for five crude oil pipelines with length 300 Km.

Al-Samra wastewater treatment plant monitoring and assessment, This project involved setting up monitoring programs, conducting training programs, reviewing monitoring performance and provide solutions to the problems encountered in running the plant.

Integrated wastewater management policies for marginal communities in Jordan, the project included social, economical, and environmental studies of selected rural area in Jordan where decentralized treatment of wastewater will be implemented. The reclaimed water is proposed to be used for irrigation.

Al- Hussien military workshops treatment plant monitoring: This project involved setting up monitoring programs, conducting training programs, reviewing monitoring performance and provide solutions to the problems encountered in running the plant.

Al – Fuheis Wastewater Treatment Plant: This project involved setting up monitoring programs, reviewing monitoring performance and provide solutions to the problems encountered in running the plant.

Other Projects related to Wastewater Treatment Plant projects including: Sizing the reactors, undertaking mass balance, selection of pumps, selection the process flow diagram, preparing operation and maintenance manuals and trouble shooting.

Bahrain Petroleum Company (BAPCO), *Waste Management Audit and Procedure Development* **(Senior Consultant)**

General Electric (GE)**, *Environmental Compliance Audit and Category II Environmental Assessment at the General Electric's MEELSA/MEPCO Dammam service center*** (Senior Consultant)

SABIC- IBN ZHR, ***A 3-day internal Auditors training as part of the Implementation phase of Occupational Health and Safety Management System in line with the requirements of OHSAS 18001 management system*** (Consultant)

Saudi Arabian Oil Company (ARAMCO), *Consultancy and Training Services for the Development of an Environmental Management System at the PD&T department in Compliance to the Requirements of ISO 14001:2004 standard* **(Project Manager)**

SABIC- IBN SINA, *Providing Consultancy and Support for the Development and Implementation of Occupational Health and Safety Management System in line with the requirements of OHSAS 18001 management system* **(Consultant)**

SABIC- PETROKEMYA, *Development and Implementation of Occupational Health and Safety Management System in line with the requirements of OHSAS 18001 management system and Integration of EMS and OH&S Management systems* **(Consultant)**

Bahrain Petroleum Company (Bapco), *Development and Implementation of Environmental Management System in line with the requirements of ISO14001:2004 18001* **(Senior Consultant)**

Simon India Limited (SIL), *Preparation of the Environmental Information Report and Best Available Technology (BAT) Analysis for the installation of Ammonia abatement technology at SAFCO and IBB plants, SABIC* **(Senior Consultant)**

MADA Saudi Waterproofing Company, *Air Dispersion Modeling study to determine the optimal stack height of the stack.* **(Consultant)**